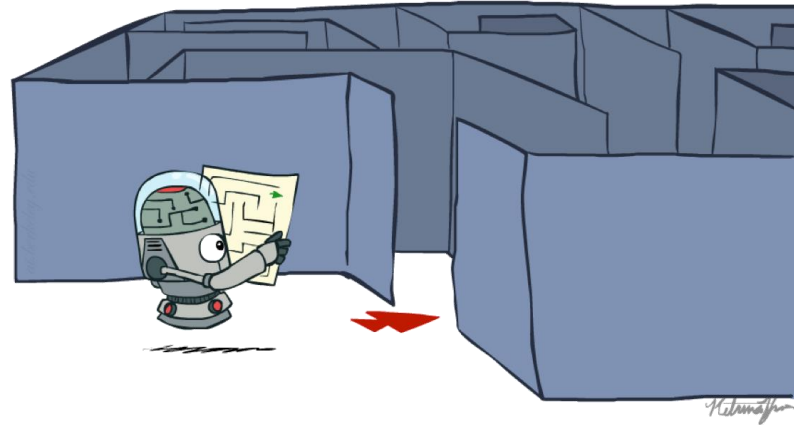


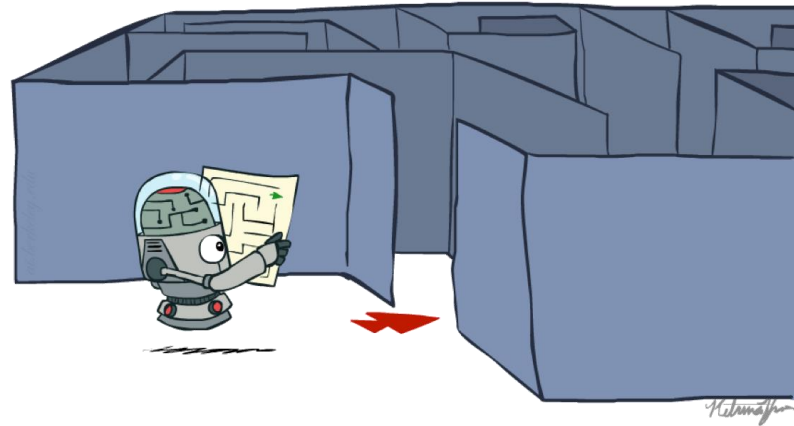
AI-Module 1



Georges Sakr
ESIB

What is AI?

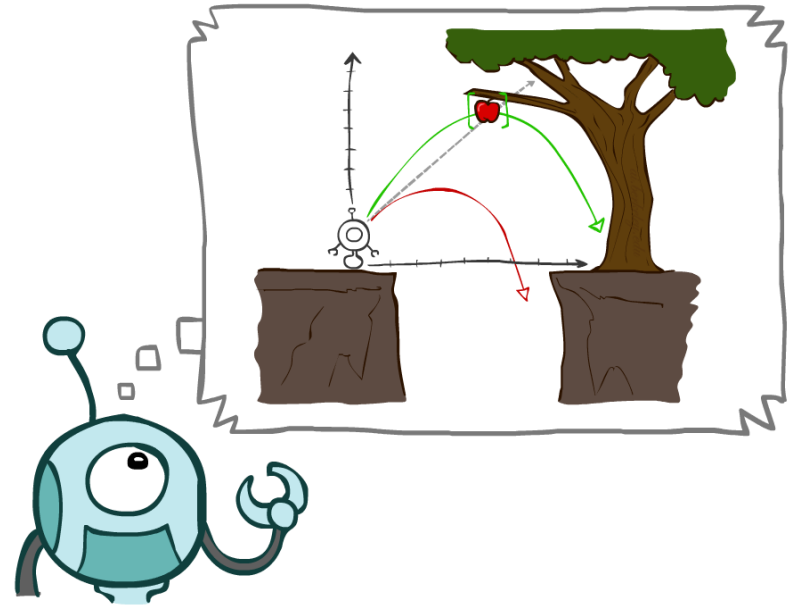
Search Problems



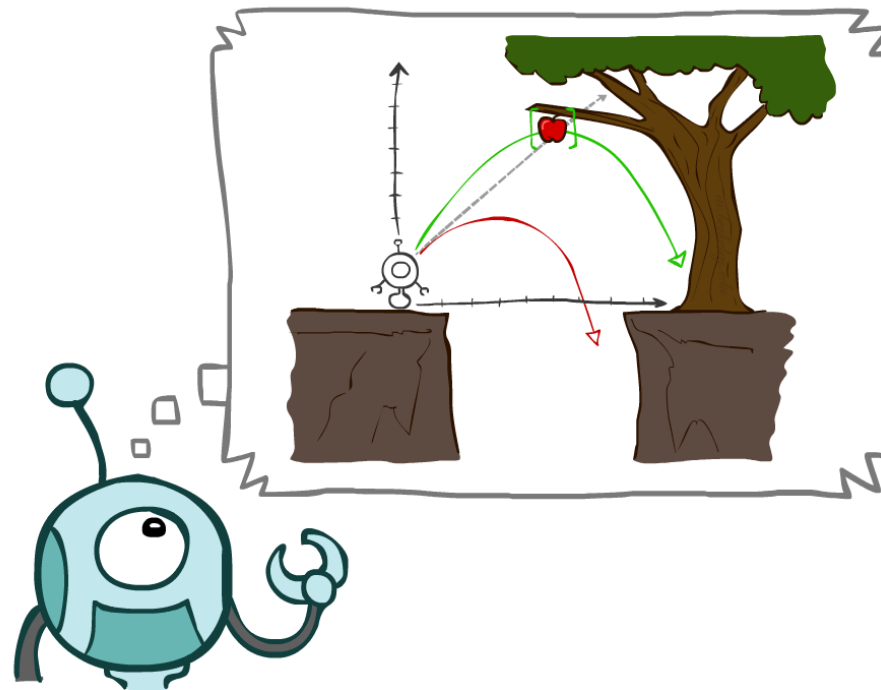
Georges Sakr
ESIB

Today

- Agents that Plan Ahead
- Search Problems
- Uninformed Search Methods
 - Depth-First Search
 - Breadth-First Search
 - Uniform-Cost Search

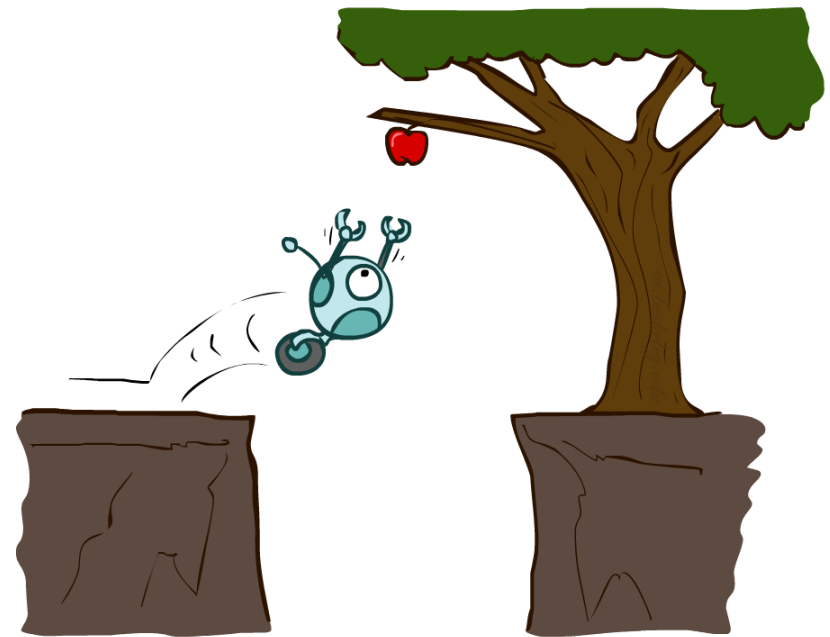


Agents that Plan



Reflex Agents

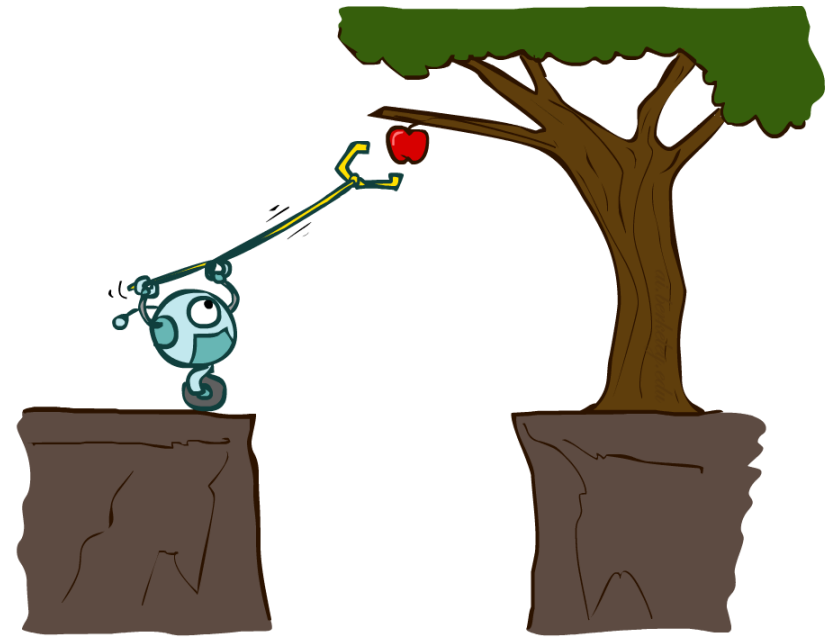
- Reflex agents:
 - Choose action based on current percept (and maybe memory)
 - May have memory or a model of the world's current state
 - Do not consider the future consequences of their actions
 - Consider how the world IS
- Can a reflex agent be rational?



[Demo: reflex optimal (L2D1)]

Planning Agents

- Planning agents:
 - Ask “what if”
 - Decisions based on (hypothesized) consequences of actions
 - Must have a model of how the world evolves in response to actions
 - Must formulate a goal (test)
 - Consider how the world **WOULD BE**
- Optimal vs. complete planning
- Planning vs. replanning



[Demo: replanning (L2D3)]

Search Problems



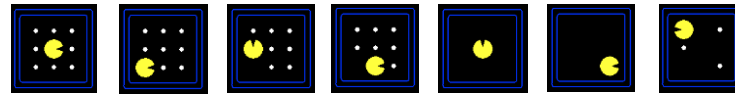
Search Problems

- A search problem consists of:

Search Problems

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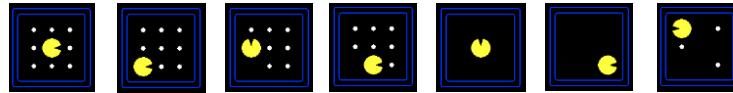
- A state space



Search Problems

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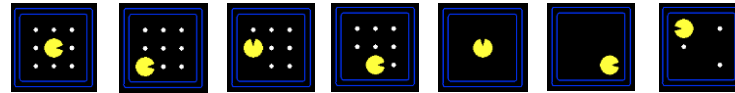


- A successor function
(with actions, costs)

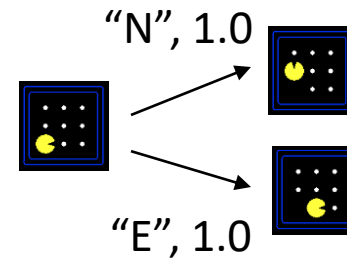
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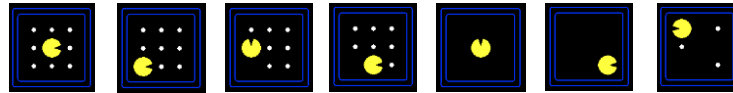
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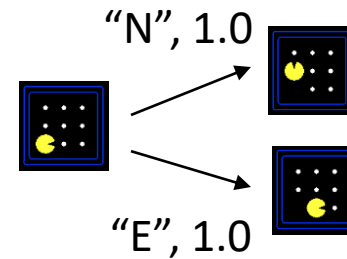
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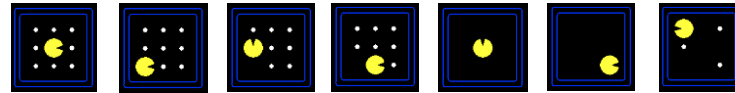


- A start state and a goal test

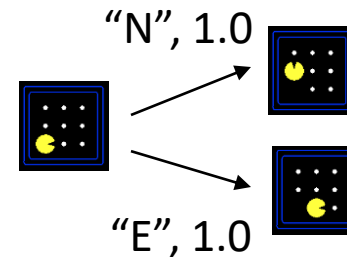
Search Problems

- A **search problem** consists of:

- A state space



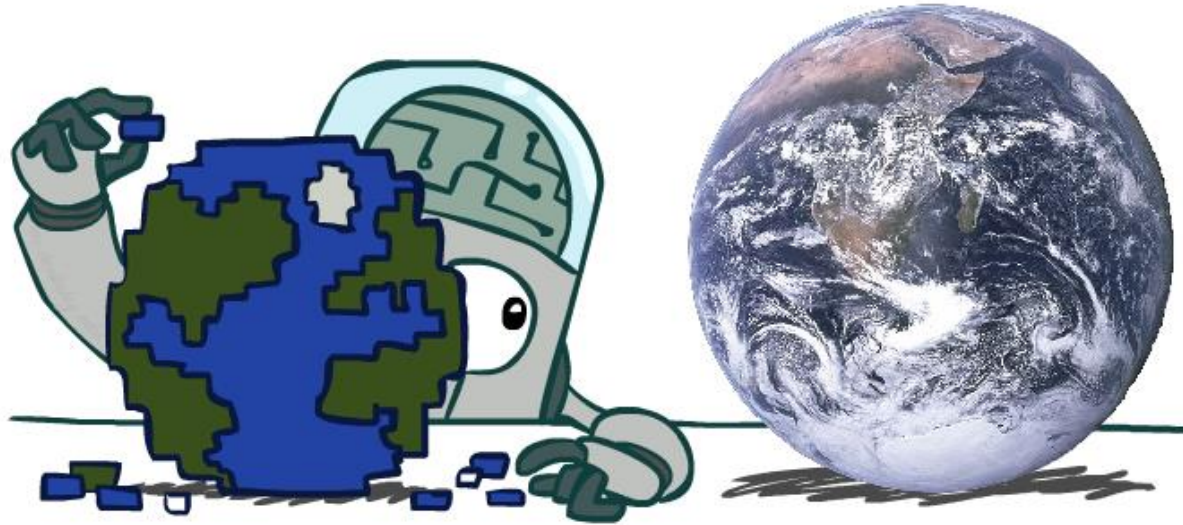
- A successor function
(with actions, costs)



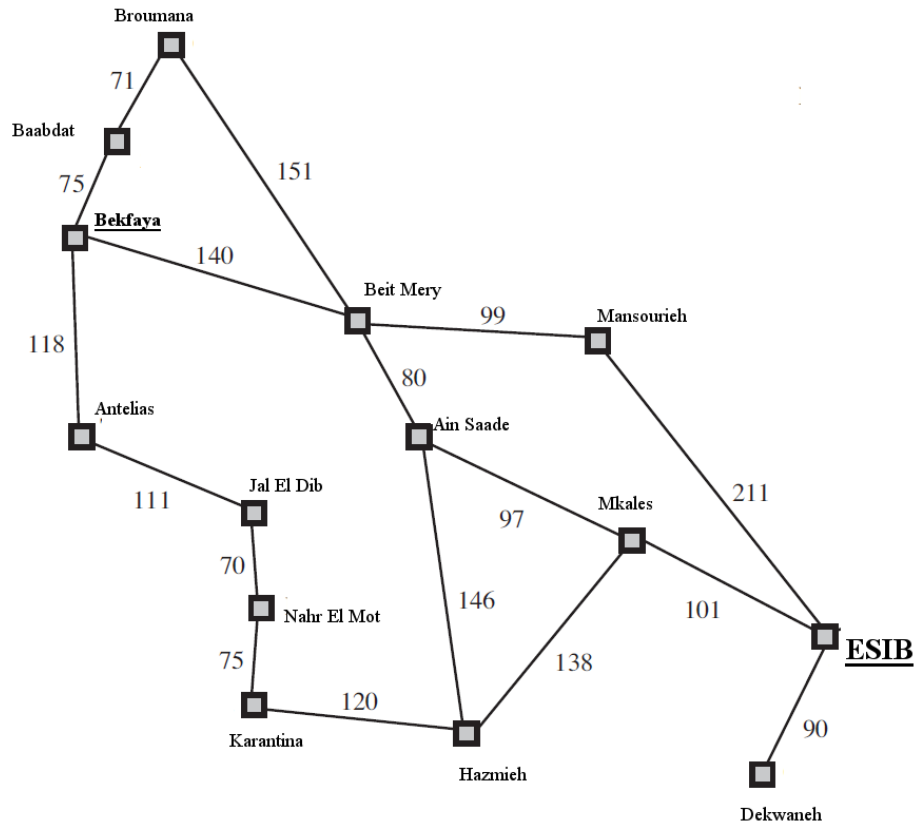
- A start state and a goal test
- A **solution** is a sequence of actions (a plan) which transforms the start state to a goal state

Search Problems Are Models

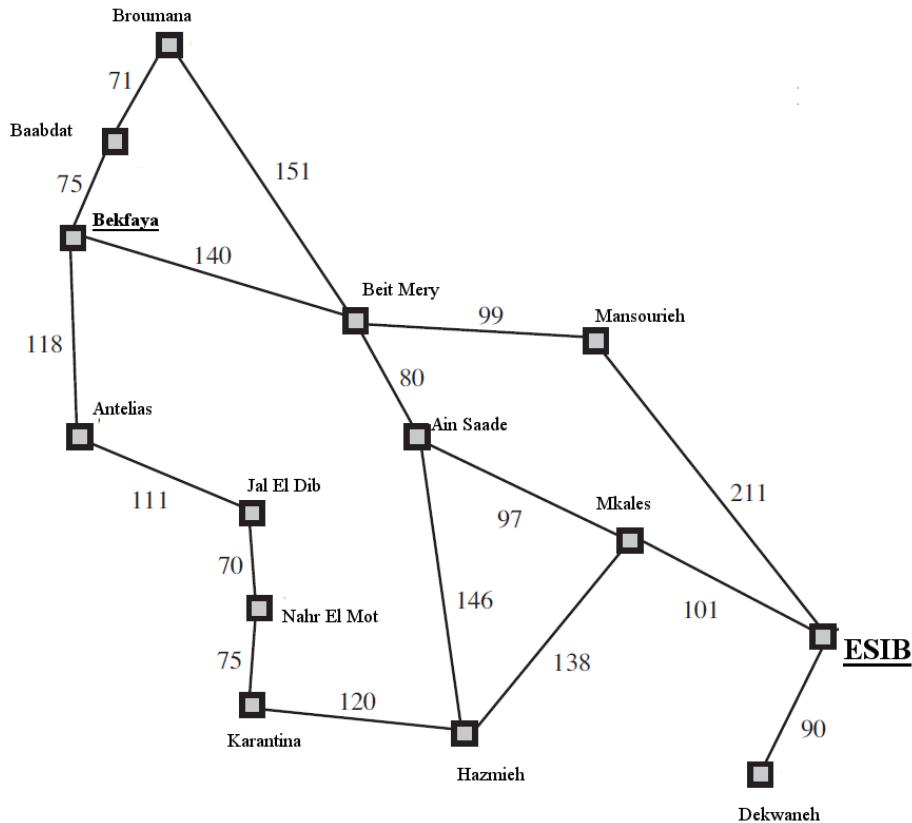
Search Problems Are Models



Example: Going to ESIB

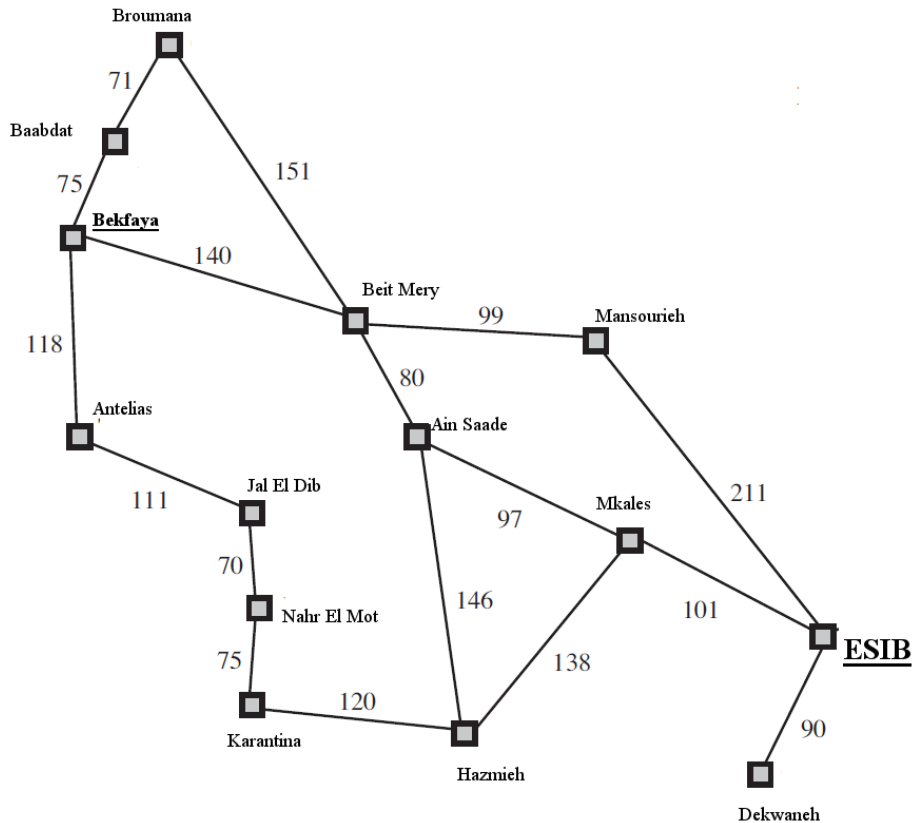


Example: Going to ESIB



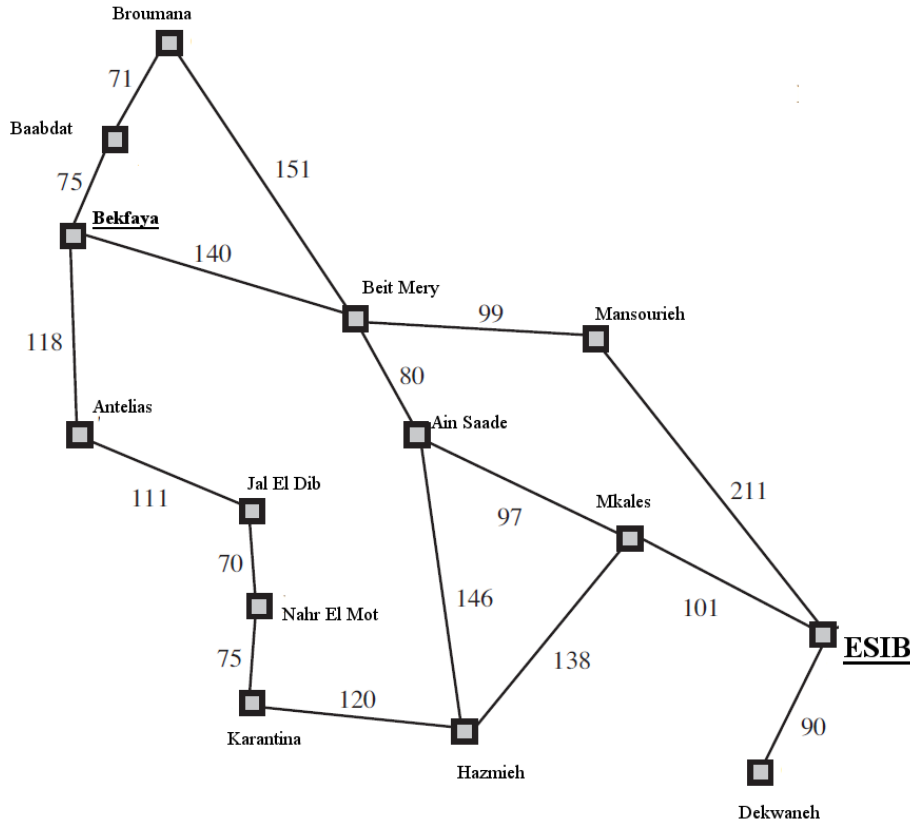
■ State space:

Example: Going to ESIB



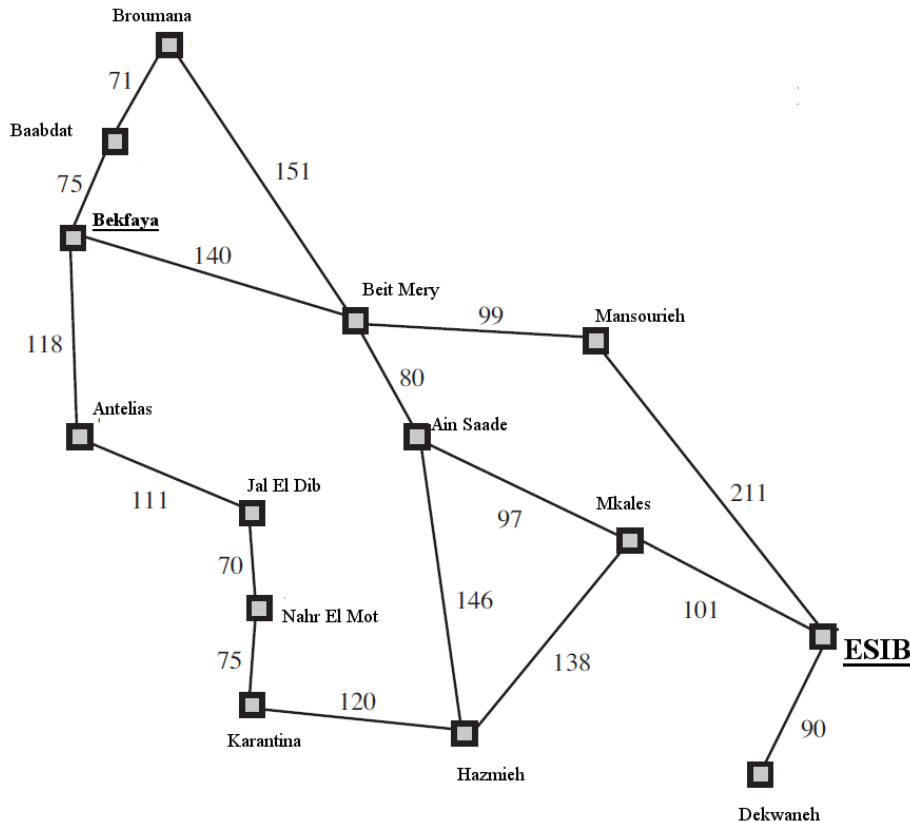
- State space:
- Cities

Example: Going to ESIB



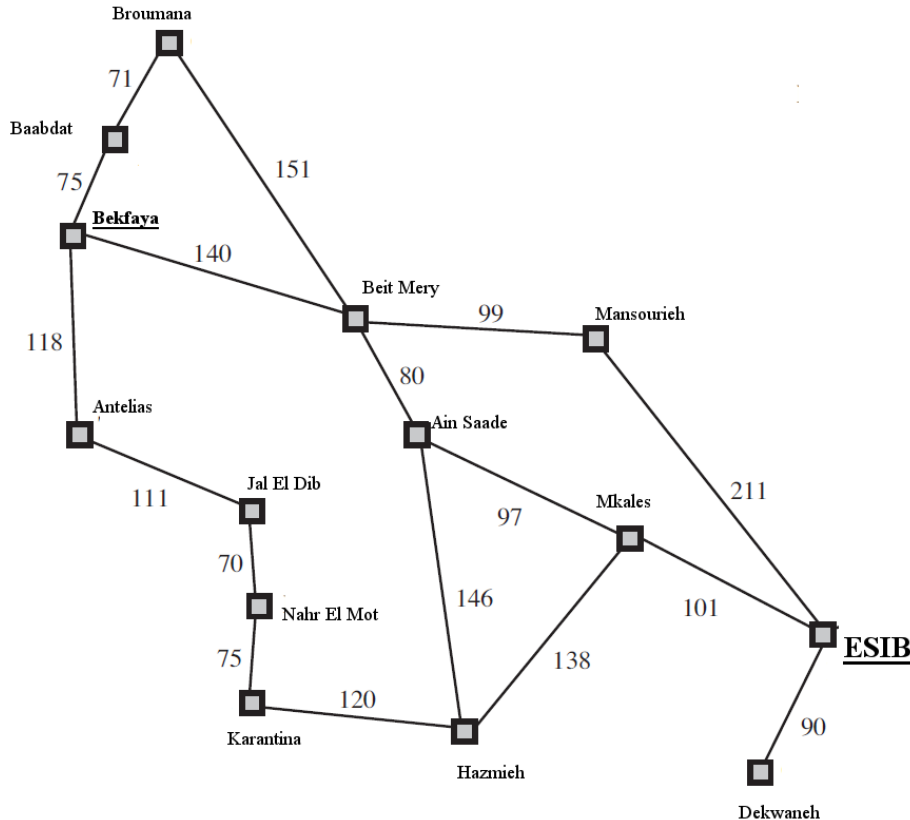
- State space:
 - Cities
- Successor function:

Example: Going to ESIB



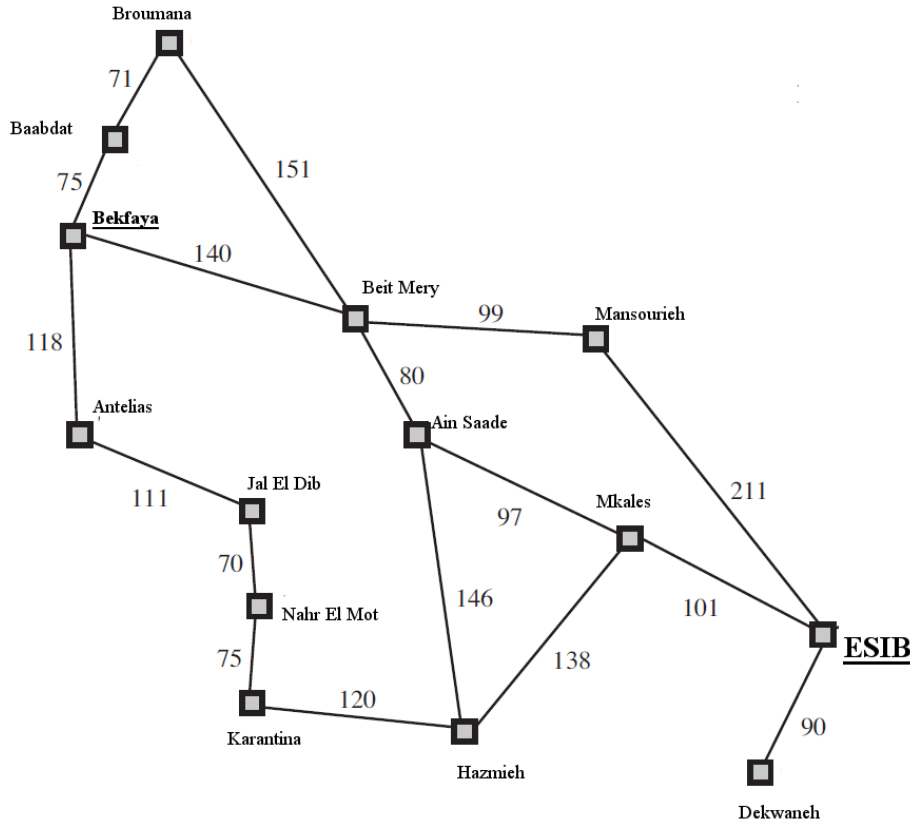
- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance

Example: Going to ESIB



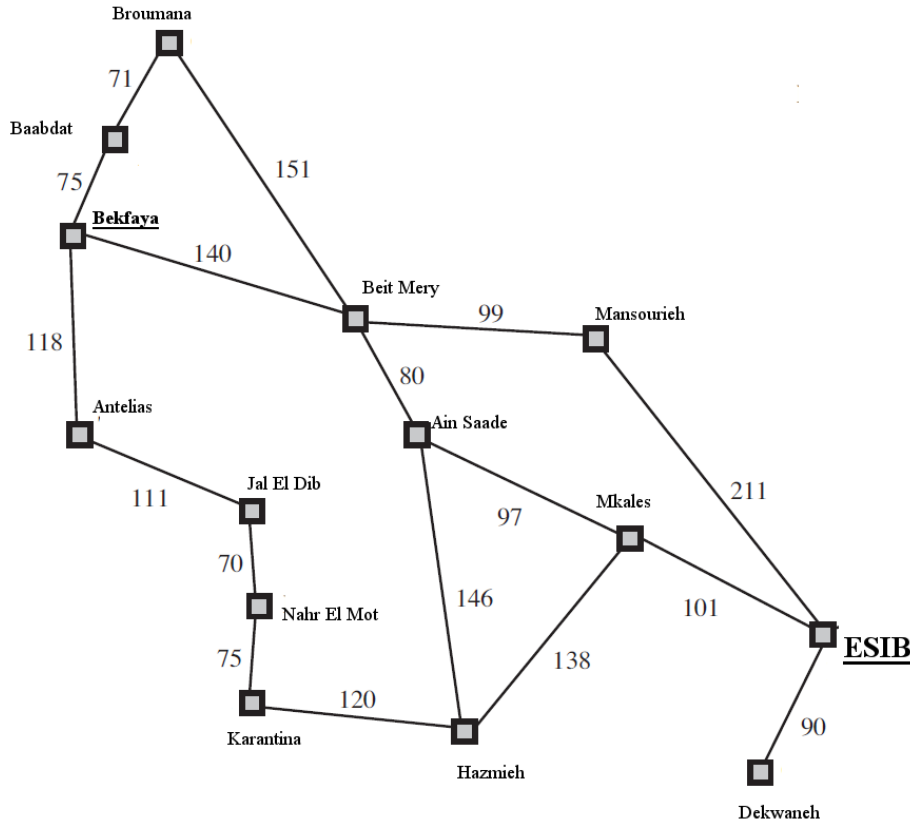
- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance
- Start state:

Example: Going to ESIB



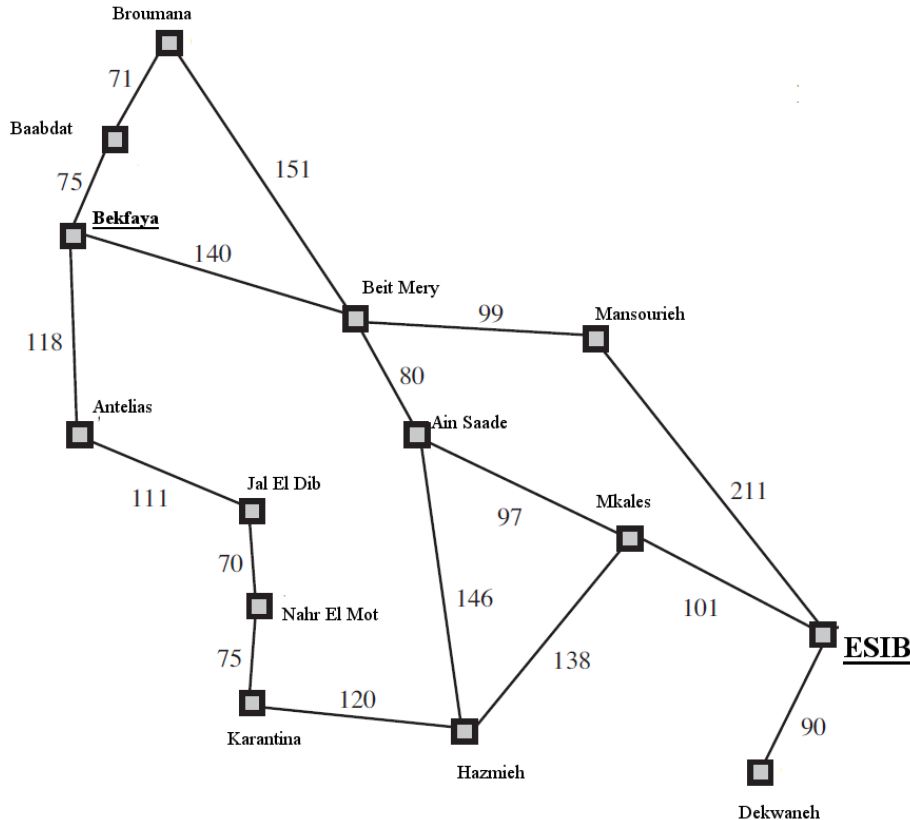
- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance
- Start state:
 - Bekfaya

Example: Going to ESIB



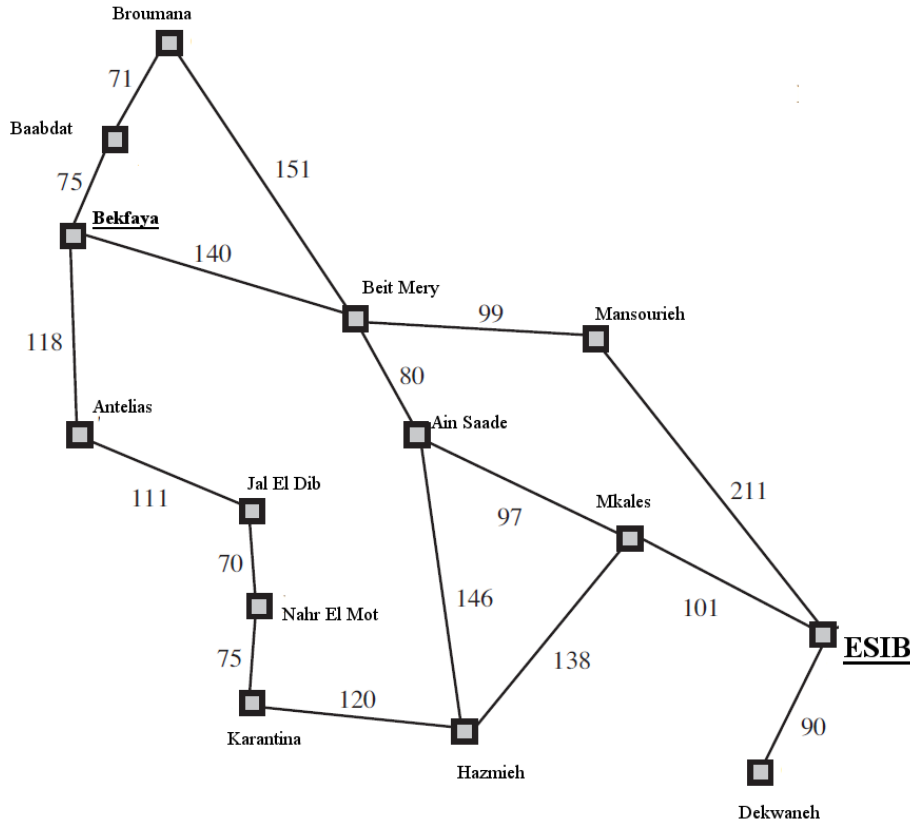
- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance
- Start state:
 - Bekfaya
- Goal test:

Example: Going to ESIB



- State space:
 - Cities
- Successor function:
 - Roads: Go to adjacent city with cost = distance
- Start state:
 - Bekfaya
- Goal test:
 - Is state == ESIB?

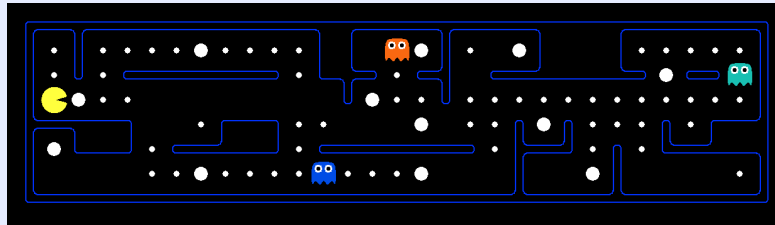
Example: Going to ESIB



- State space:
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- Successor function:
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- Start state:
 - Bekfaya
- Goal test:
 - Is state == ESIB?
- Solution?

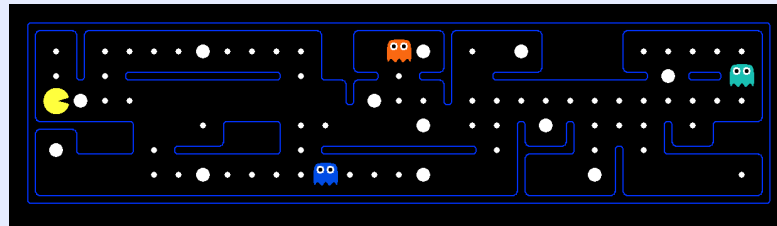
What's in a State Space?

The **world state** includes every last detail of the environment



What's in a State Space?

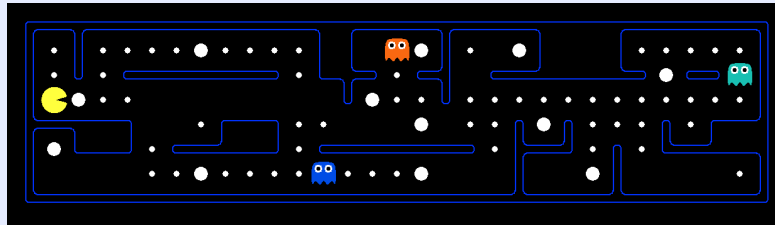
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A **search state** keeps only the details needed for planning (abstraction)

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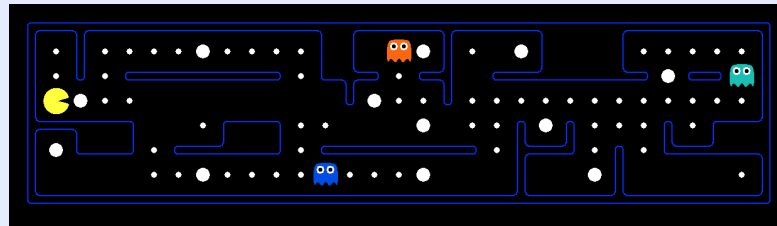


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- Problem: Pathing

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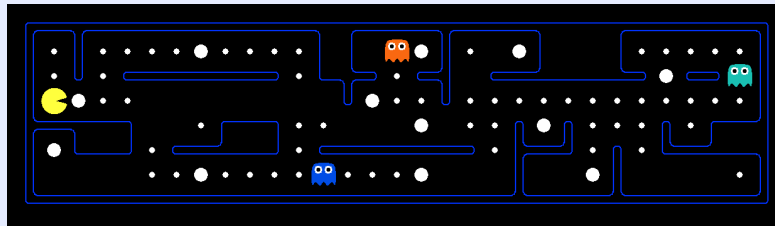


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- **Problem: Pathing**
 - States: (x,y) location

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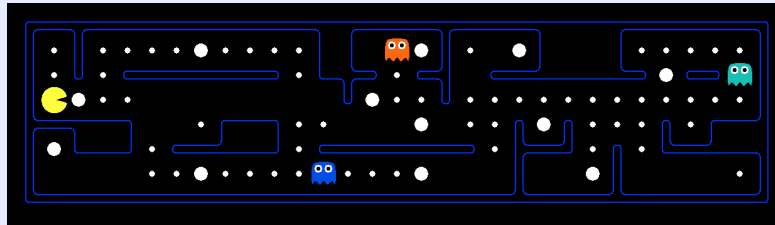


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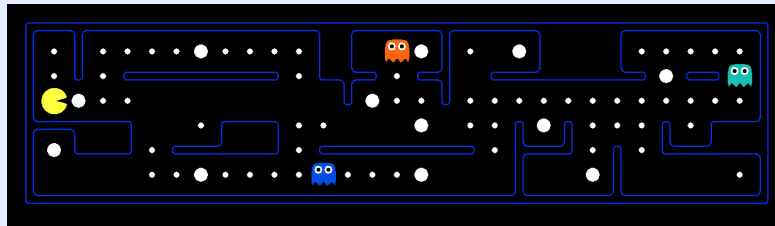


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- **Problem: Pathing**
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 - Successor: update location only

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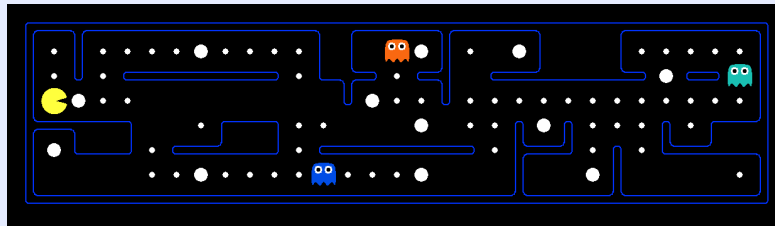


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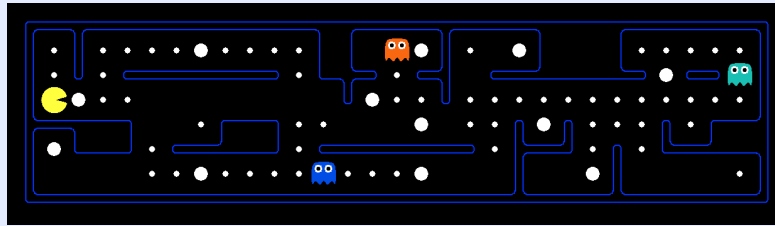


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- **Problem: Pathing**
 - States: (x,y) location
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- **Problem: Eat-All-Dots**

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■ Problem: Pathing

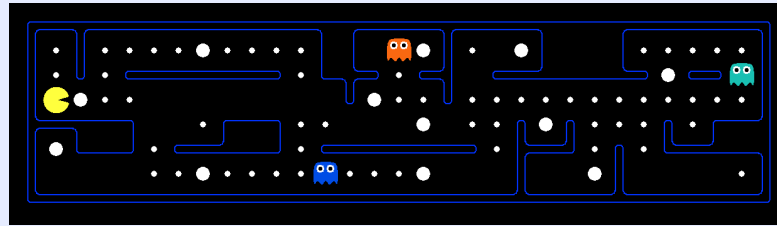
- States: (x,y) location
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- Goal test: is $(x,y)=END$

■ Problem: Eat-All-Dots

- States: $\{(x,y), \text{dot booleans}\}$

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■ Problem: Pathing

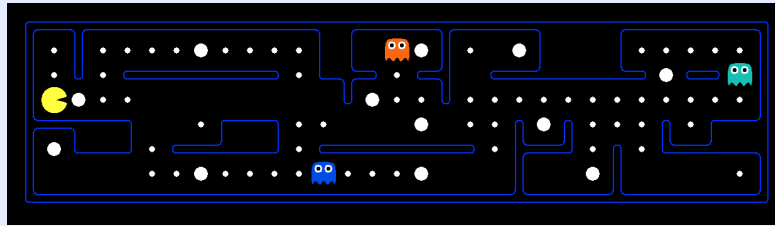
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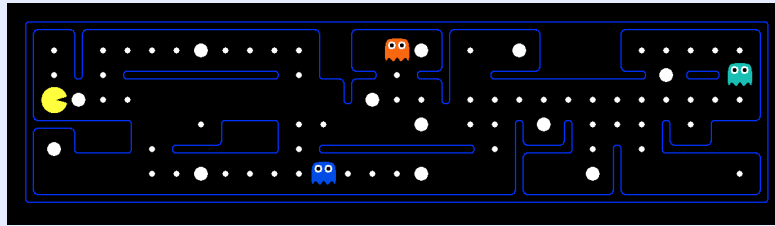
- States: (x,y) location
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- States: $\{(x,y), \text{dot booleans}\}$
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- Successor: update location and possibly a dot boolean

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■ Problem: Pathing

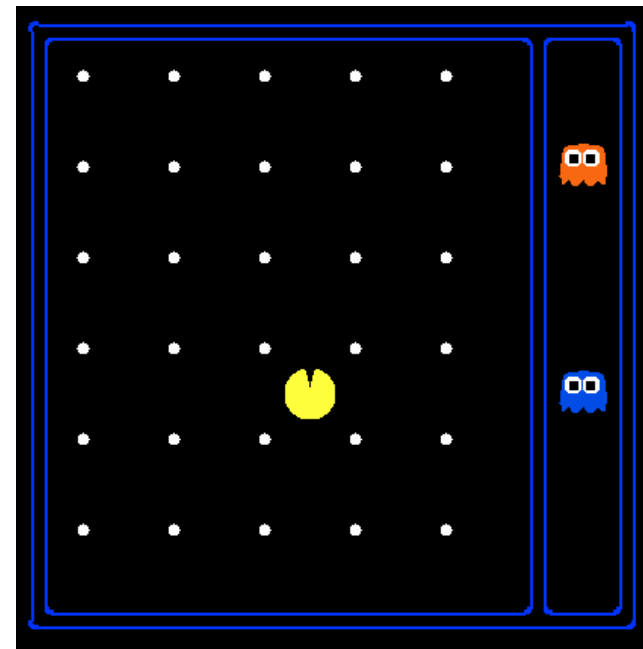
- States: (x,y) location
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- Successor: update location only
- Goal test: is $(x,y)=END$

■ Problem: Eat-All-Dots

- States: $\{(x,y), \text{dot booleans}\}$
- Actions: NSEW
- Successor: update location and possibly a dot boolean
- Goal test: dots all false

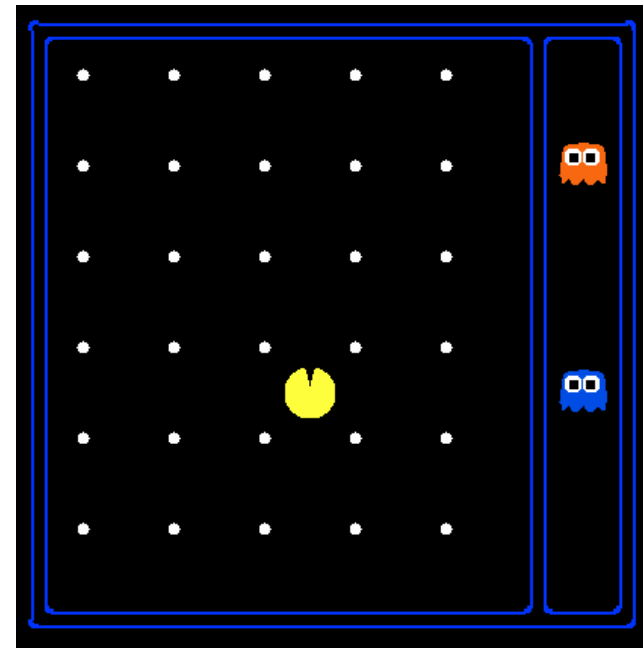
State Space Sizes?

- World state:
 - Agent positions: 120
 - Food count: 30
 - Ghost positions: 12
 - Agent facing: NSEW



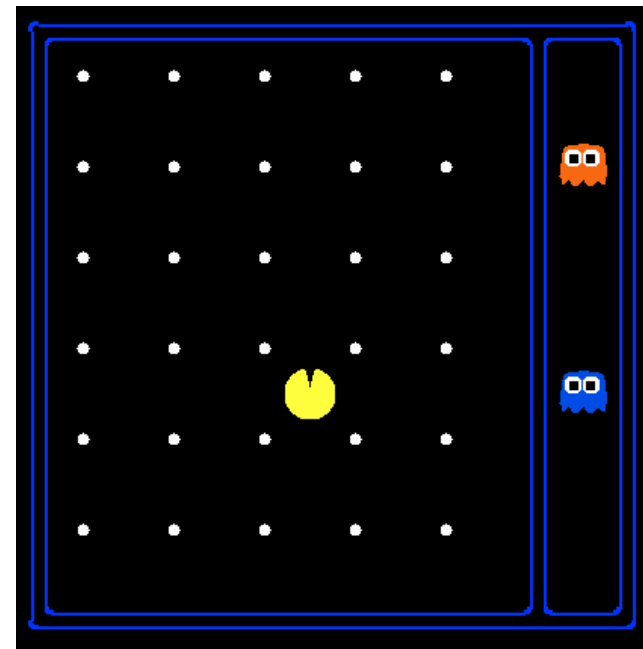
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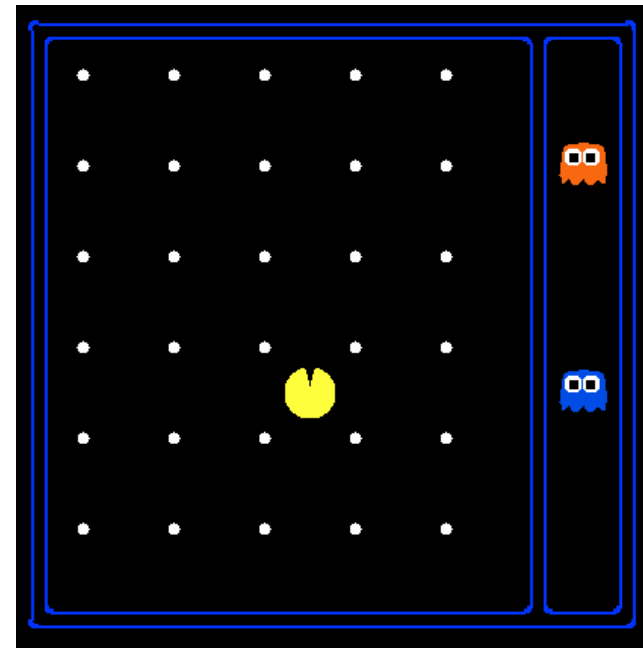
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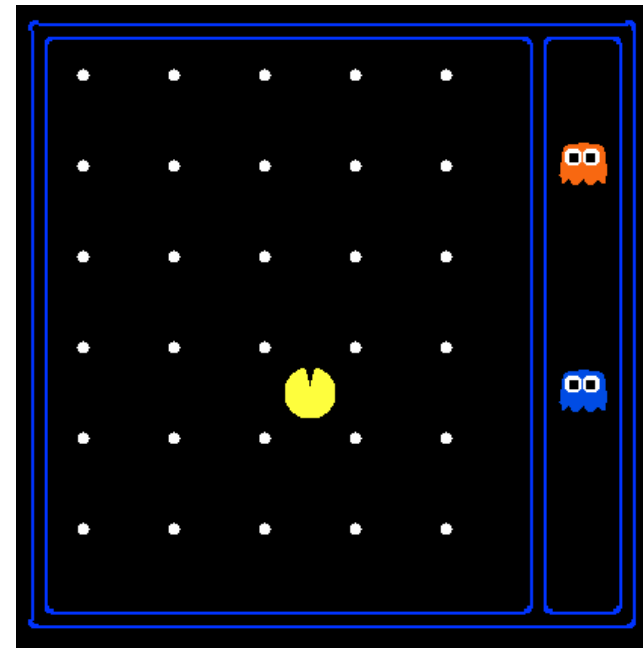
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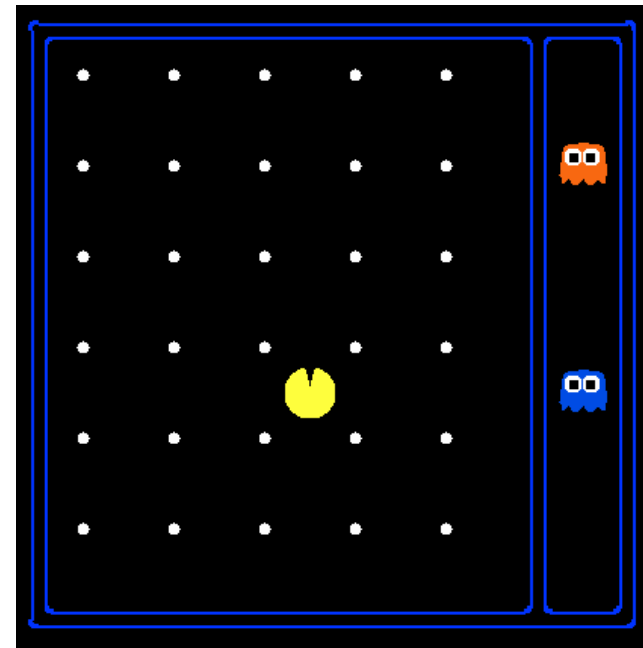
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 $120 \times (2^{30}) \times (12^2) \times 4$
 - States for pathing?



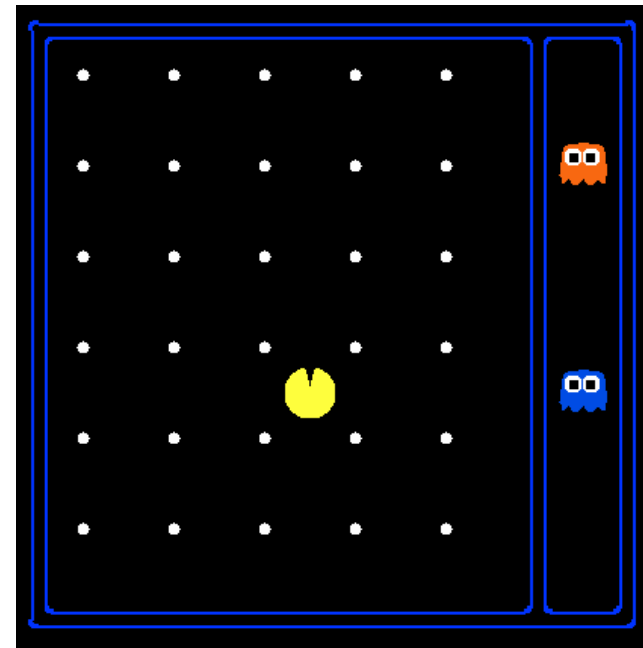
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120



State Space Sizes?

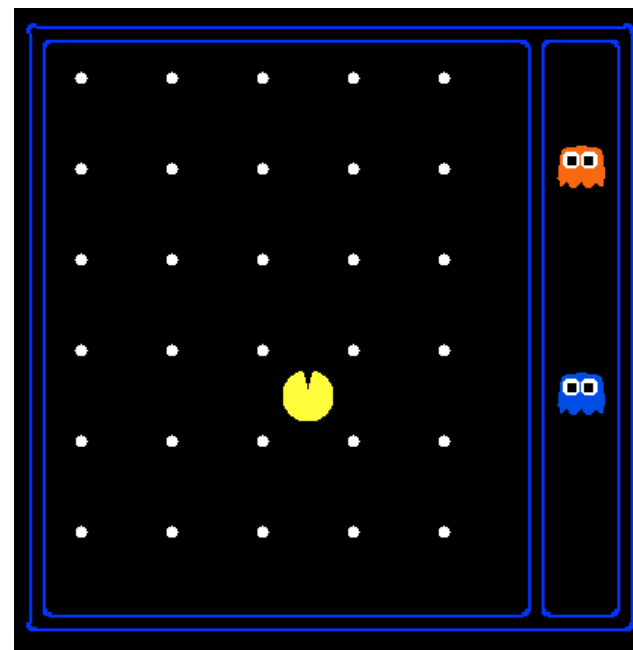
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 $120 \times (2^{30}) \times (12^2) \times 4$
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120
 - States for eat-all-dots?



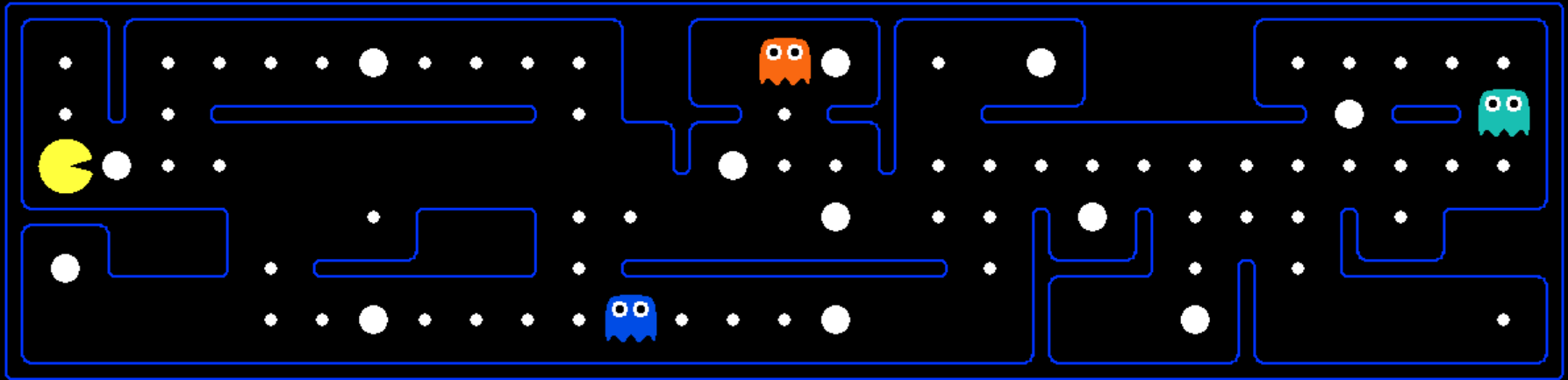
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- How many
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 $120 \times (2^{30}) \times (12^2) \times 4$
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120
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 $120 \times (2^{30})$

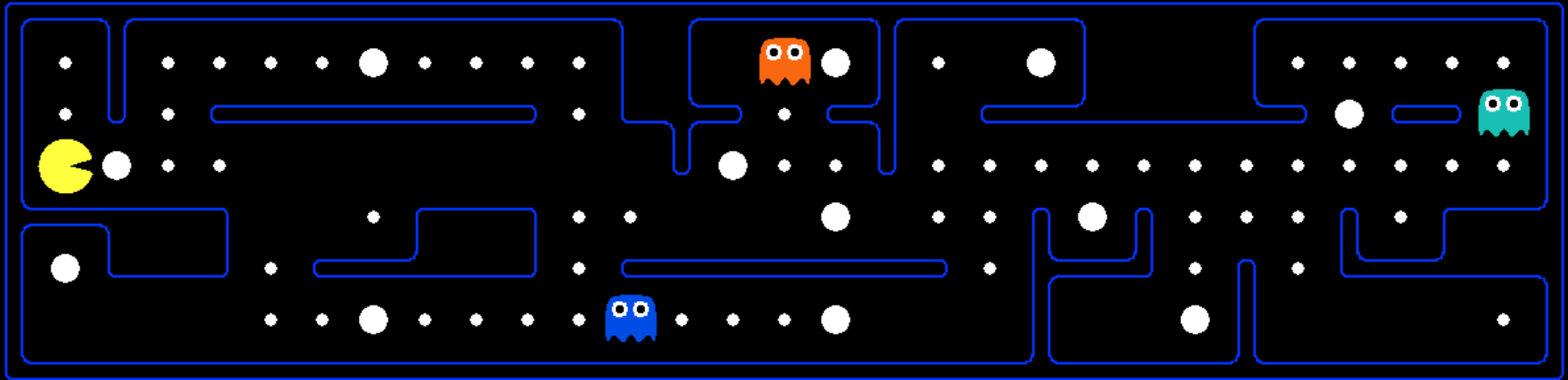


Quiz: Safe Passage



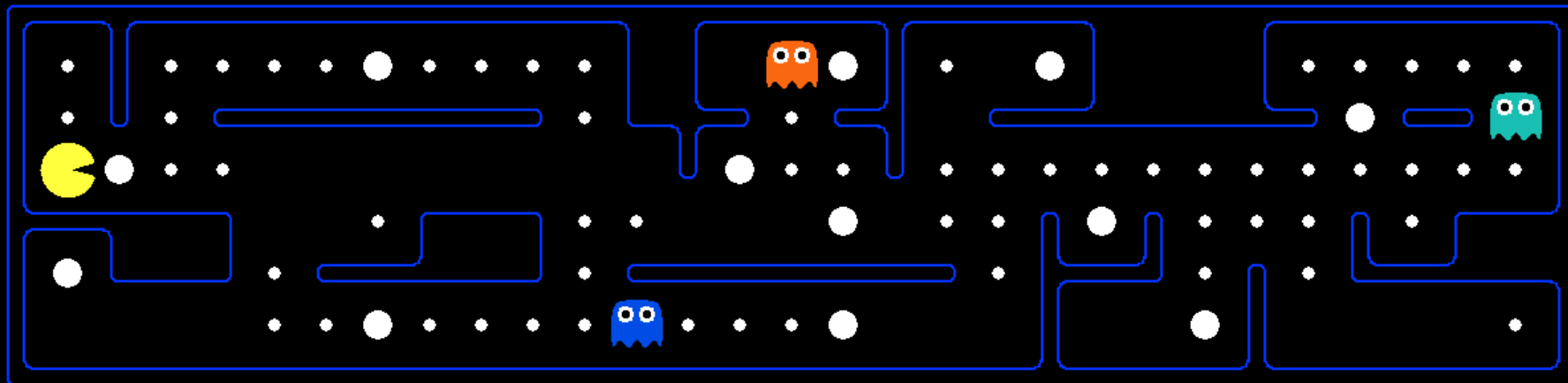
- Problem: eat all dots while keeping the ghosts perma-scared

Quiz: Safe Passage



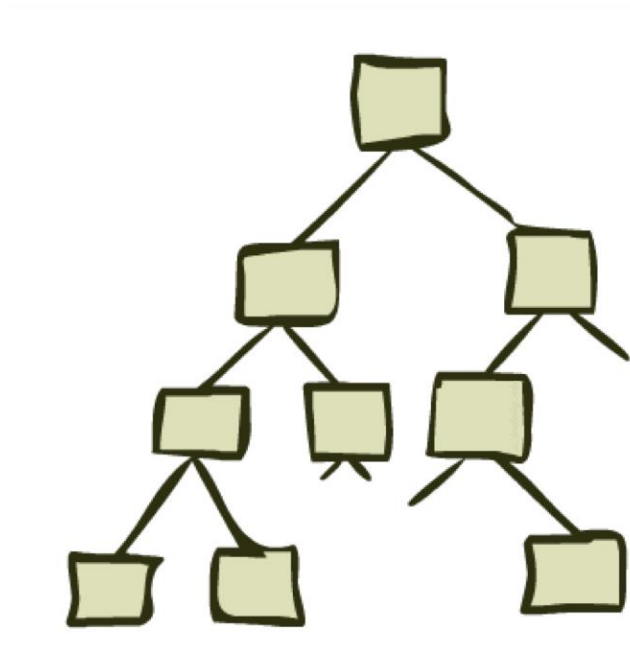
- Problem: eat all dots while keeping the ghosts perma-scared
- What does the state space have to specify?

Quiz: Safe Passage



- Problem: eat all dots while keeping the ghosts perma-scared
- What does the state space have to specify?
 - (agent position, dot booleans, power pellet booleans, remaining scared time)

State Space Graphs and Search Trees

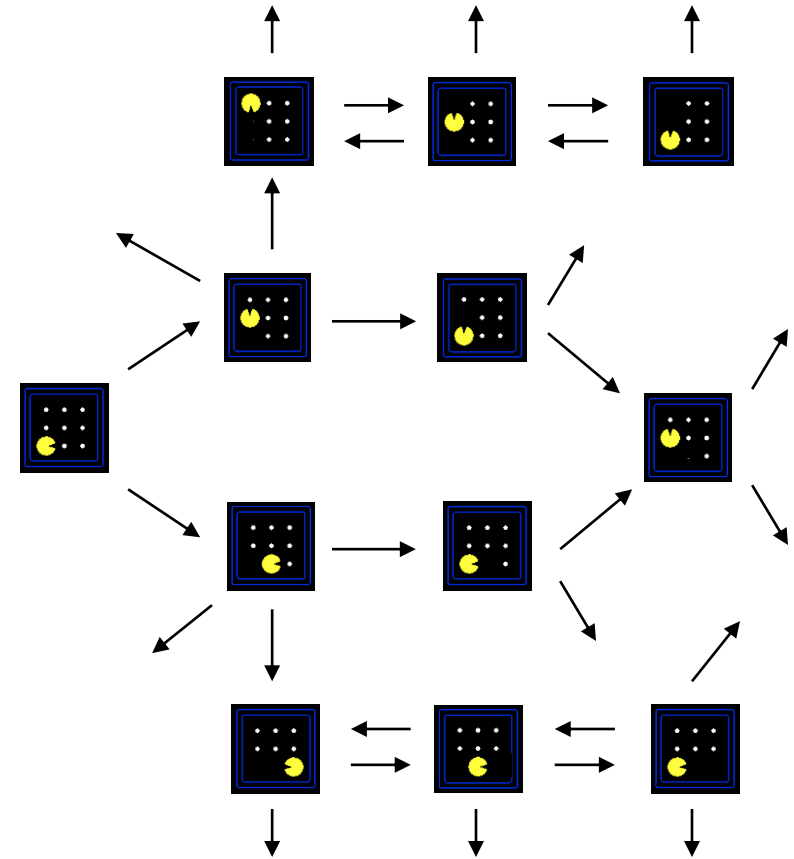


State Space Graphs

- State space graph: A mathematical representation of a search problem

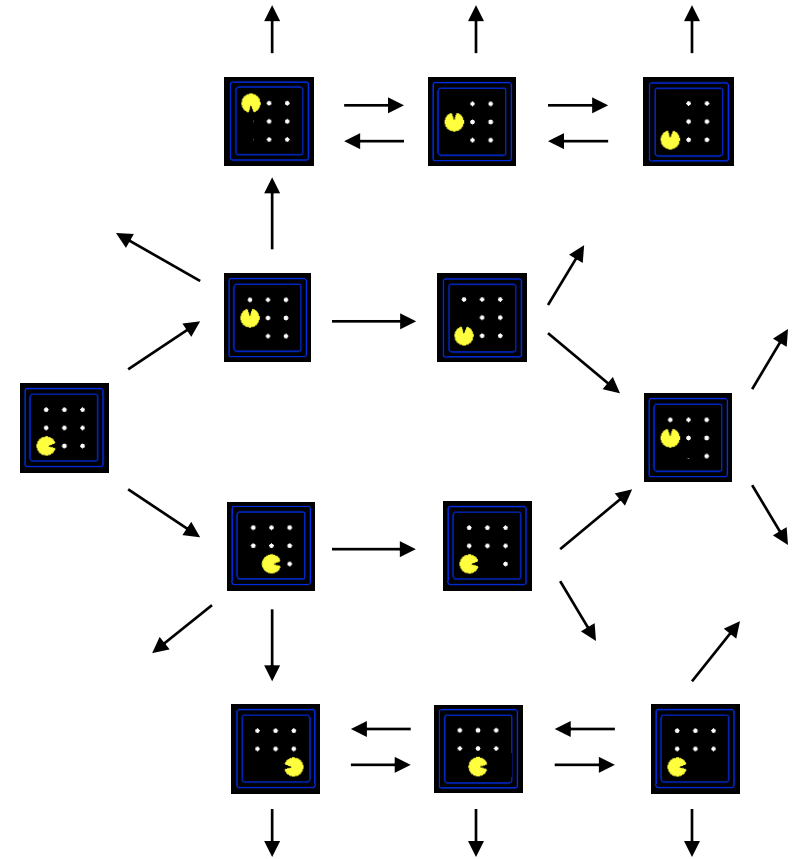
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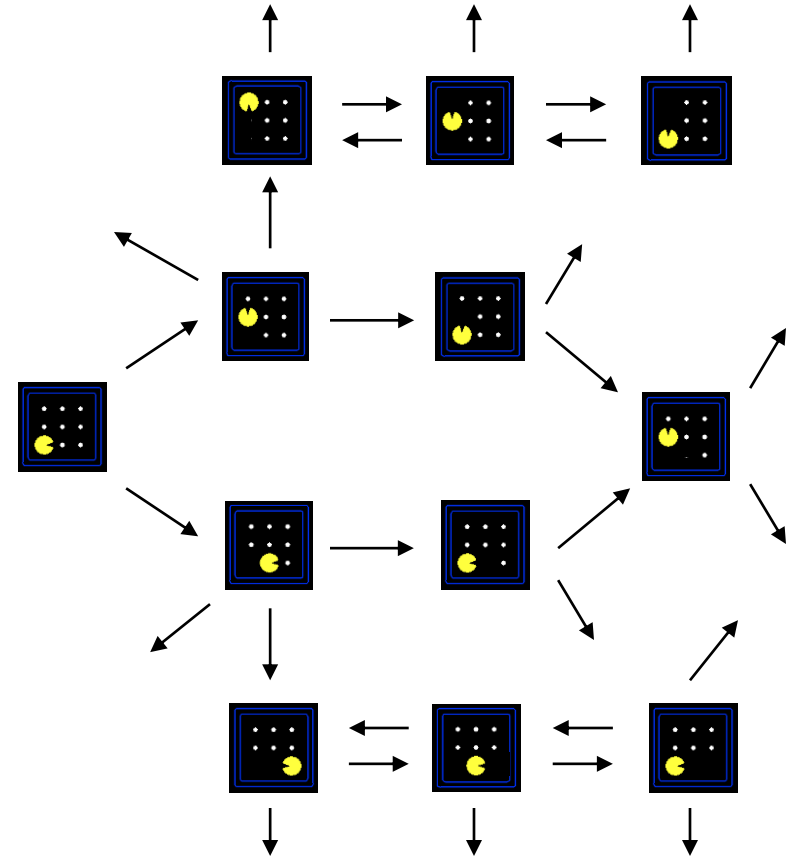
State Space Graphs

- State space graph: A mathematical representation of a search problem
 - Nodes are (abstracted) world configurations



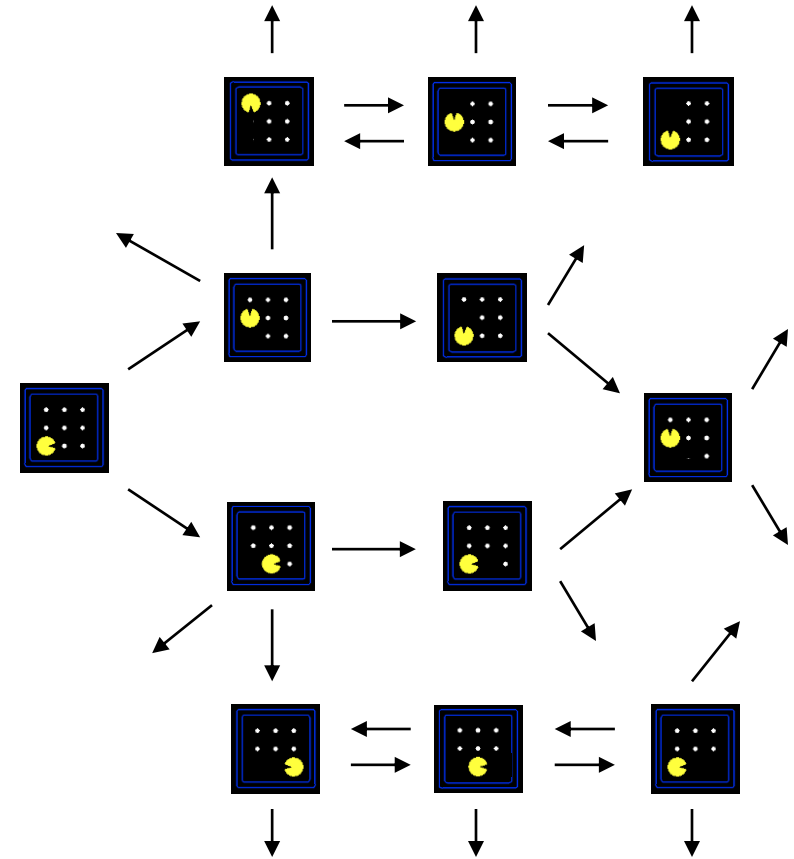
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- State space graph: A mathematical representation of a search problem
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 - Arcs represent successors (action results)



State Space Graphs

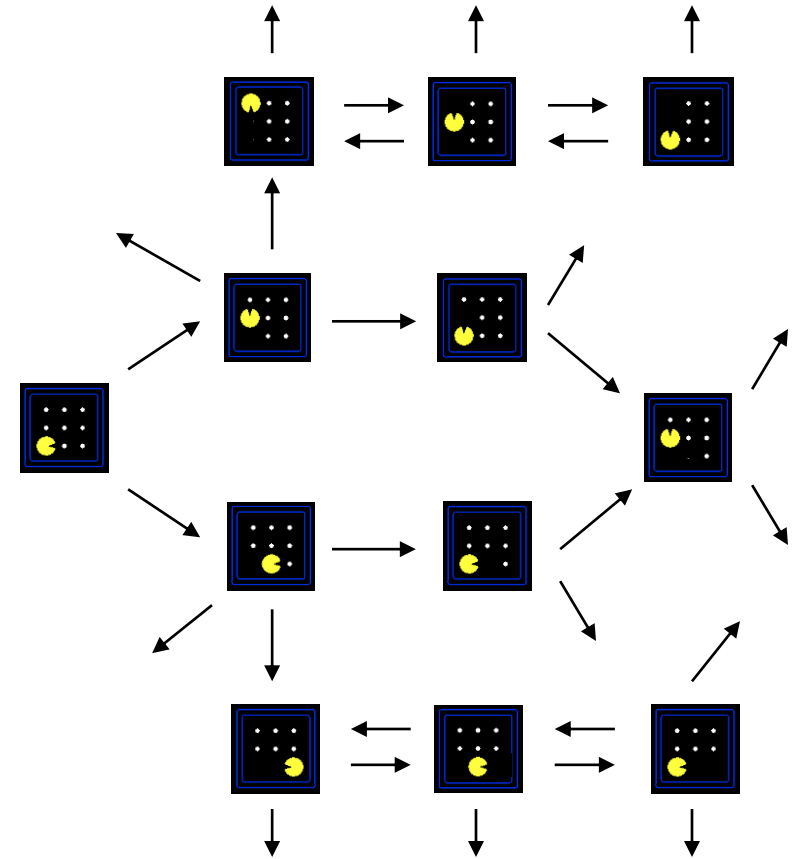
- State space graph: A mathematical representation of a search problem
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 - The goal test is a set of goal nodes (maybe only one)



State Space Graphs

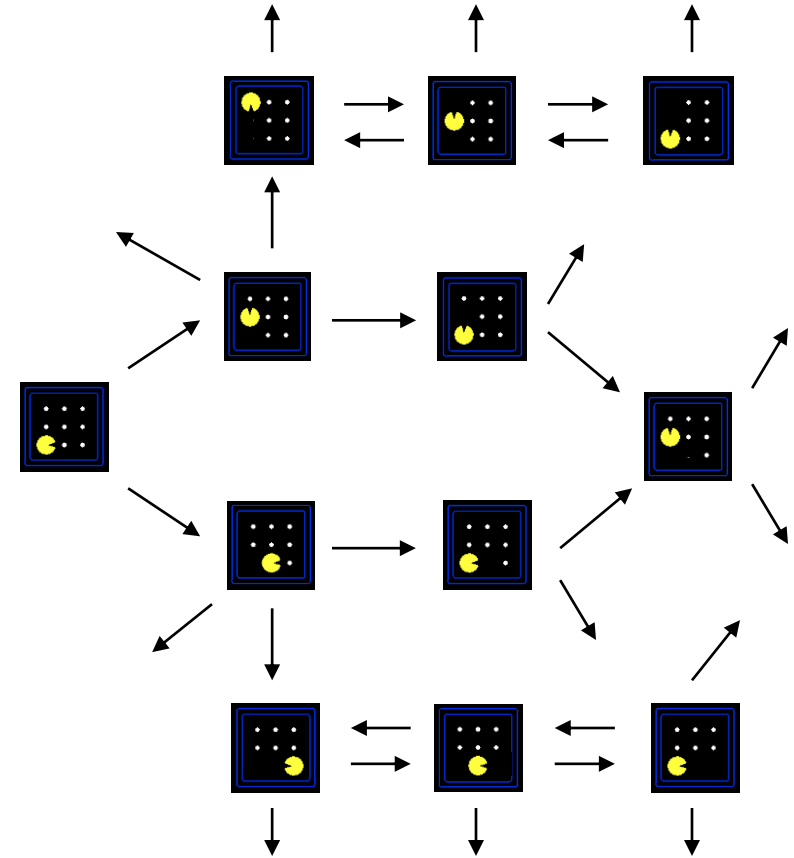
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- In a state space graph, each state occurs only once!



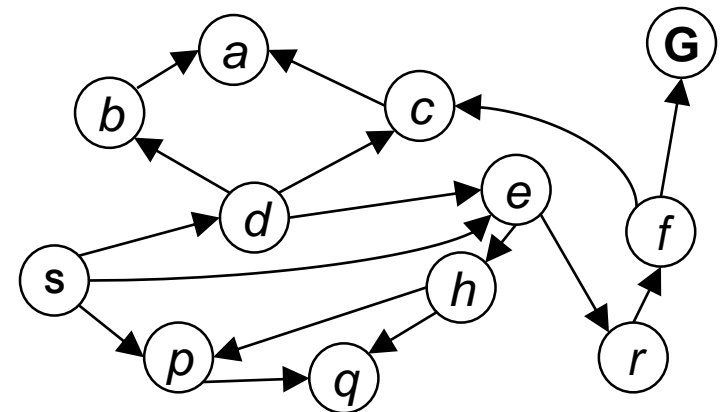
State Space Graphs

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- We can rarely build this full graph in memory (it's too big), but it's a useful idea



State Space Graphs

- State space graph: A mathematical representation of a search problem
 - Nodes are (abstracted) world configurations
 - Arcs represent successors (action results)
 - The goal test is a set of goal nodes (maybe only one)
- In a search graph, each state occurs only once!
- We can rarely build this full graph in memory (it's too big), but it's a useful idea



Tiny search graph for a tiny search problem

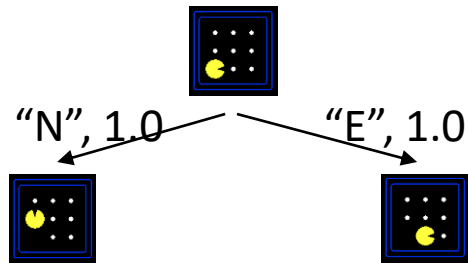
Search Trees

Search Trees



This is now / start

Search Trees

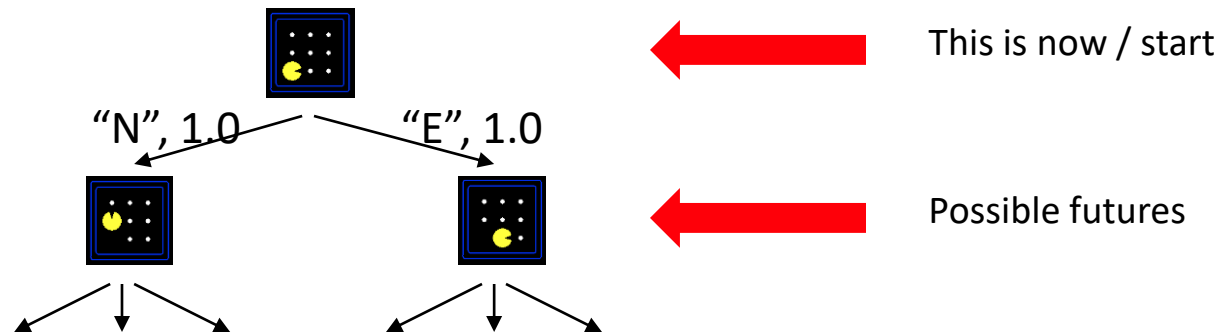


This is now / start

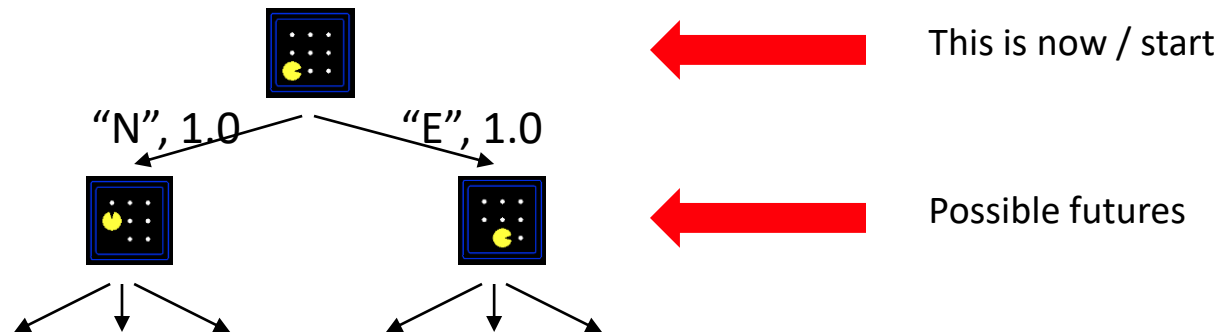


Possible futures

Search Trees



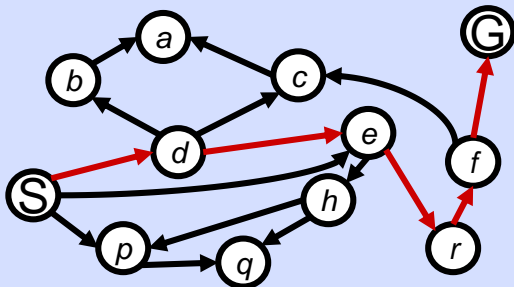
Search Trees



- A search tree:
 - A “what if” tree of plans and their outcomes
 - The start state is the root node
 - Children correspond to successors
 - Nodes show states, but correspond to PLANS that achieve those states
 - For most problems, we can never actually build the whole tree

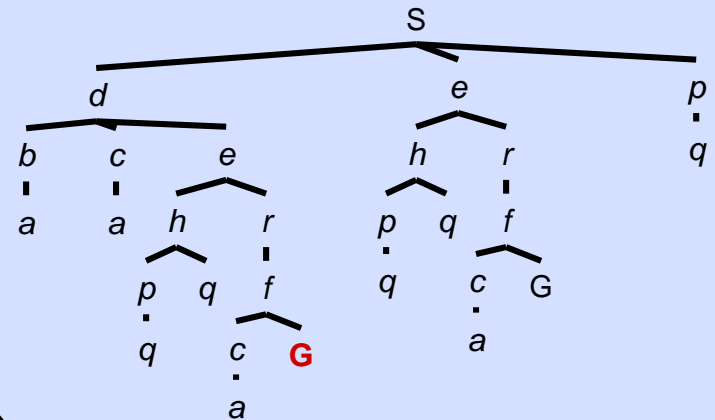
State Space Graphs vs. Search Trees

State Space Graph



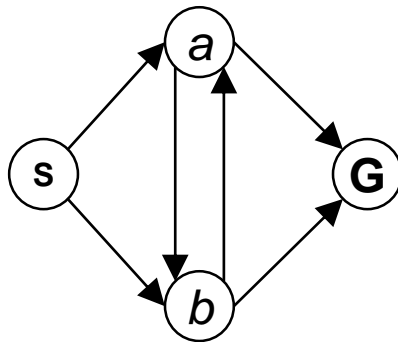
Each NODE in the search tree is an entire PATH in the state space graph. We construct both on demand – and we construct as little as possible.

Search Tree



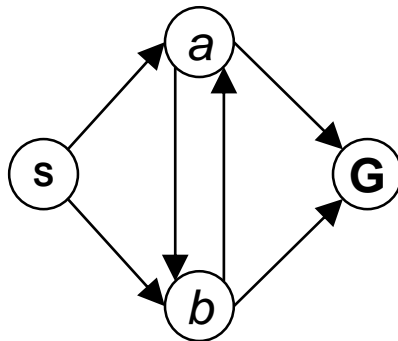
Quiz: State Space Graphs vs. Search Trees

Consider this 4-state graph:



Quiz: State Space Graphs vs. Search Trees

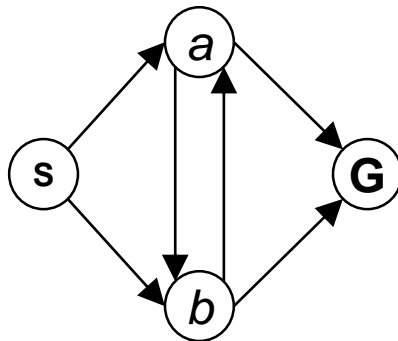
Consider this 4-state graph:



How big is its search tree (from S)?

Quiz: State Space Graphs vs. Search Trees

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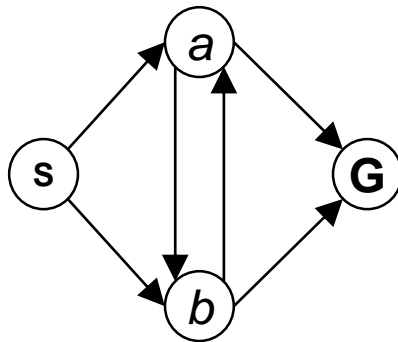


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Quiz: State Space Graphs vs. Search Trees

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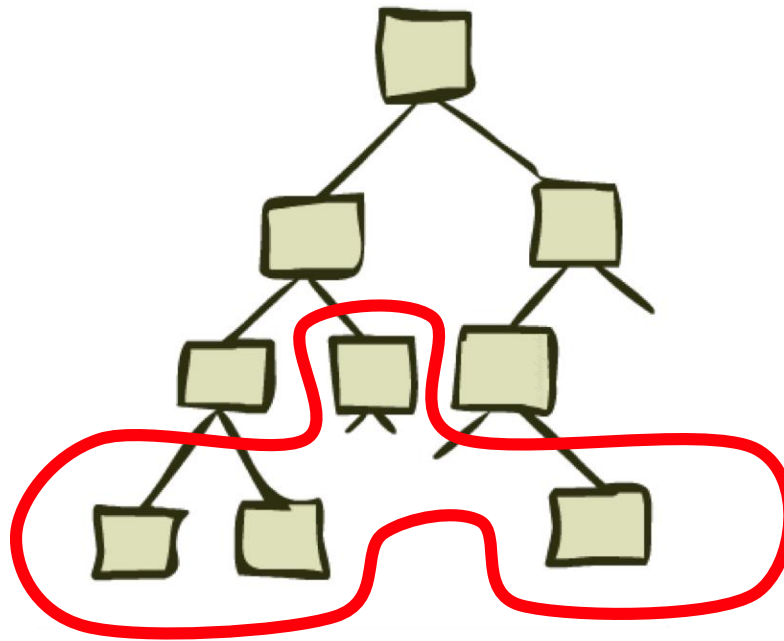


How big is its search tree (from S)?

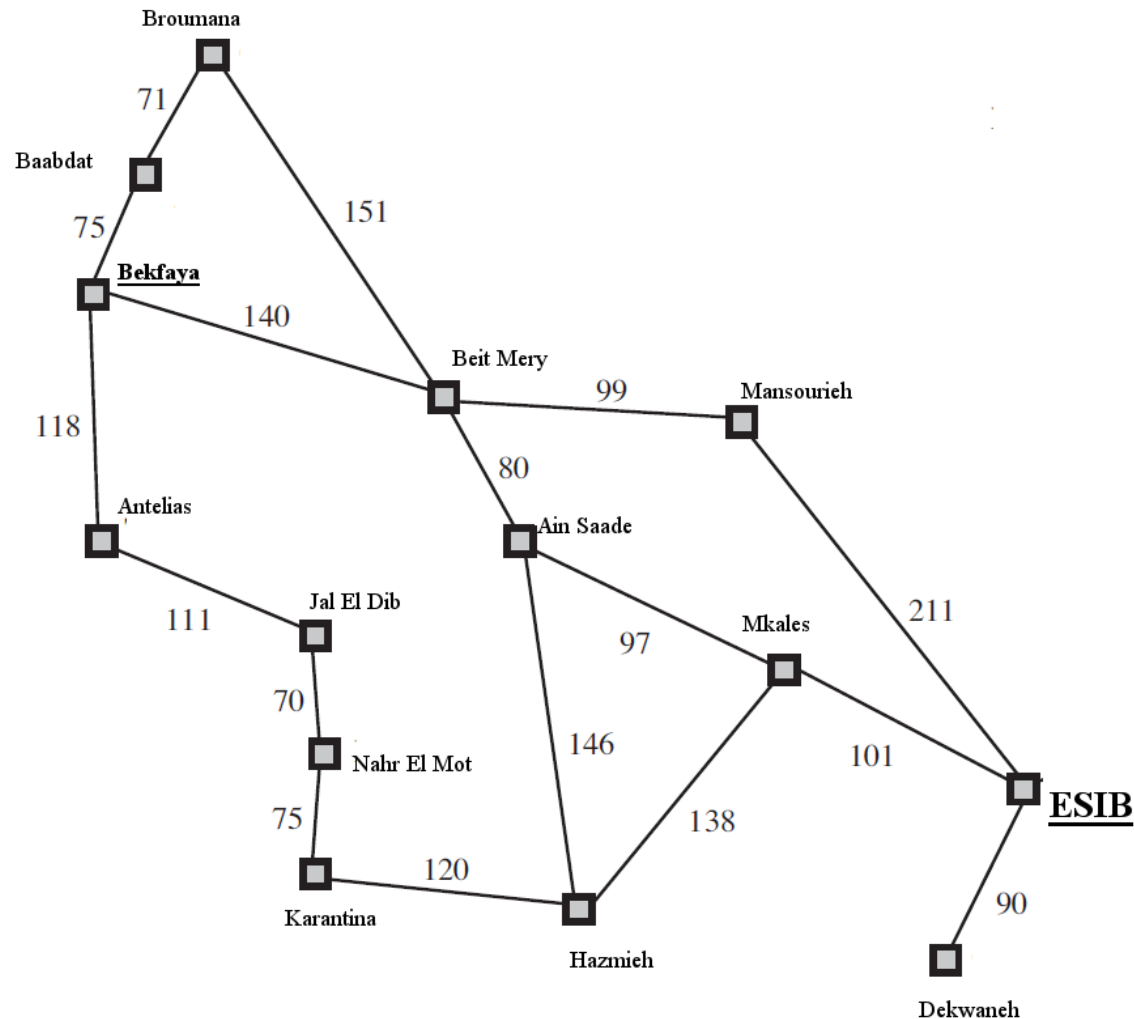


Important: Lots of repeated structure in the search tree!

Tree Search



Search Example: ESIB



Searching with a Search Tree

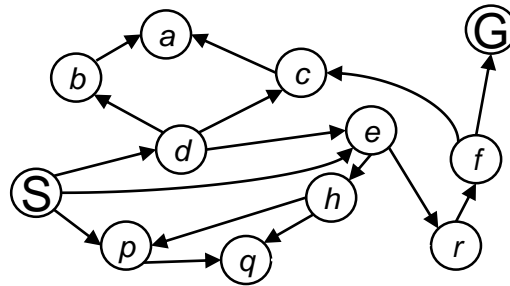
- Search:
 - Expand out potential plans (tree nodes)
 - Maintain a **fringe** of partial plans under consideration
 - Try to expand as few tree nodes as possible

General Tree Search

```
function TREE-SEARCH(problem, strategy) returns a solution, or failure
  initialize the search tree using the initial state of problem
  loop do
    if there are no candidates for expansion then return failure
    choose a leaf node for expansion according to strategy
    if the node contains a goal state then return the corresponding solution
    else expand the node and add the resulting nodes to the search tree
  end
```

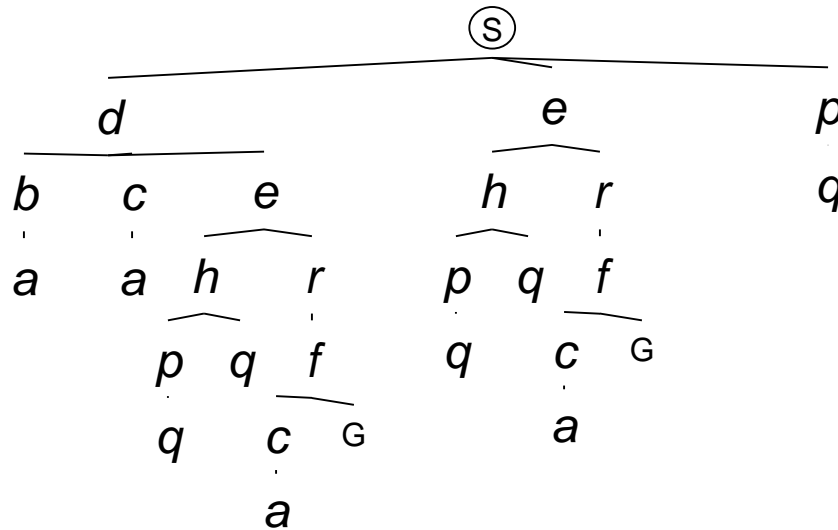
- Important ideas:
 - Fringe
 - Expansion
 - Exploration strategy
- Main question: which fringe nodes to explore?

Example: Tree Search



Depth-First Search

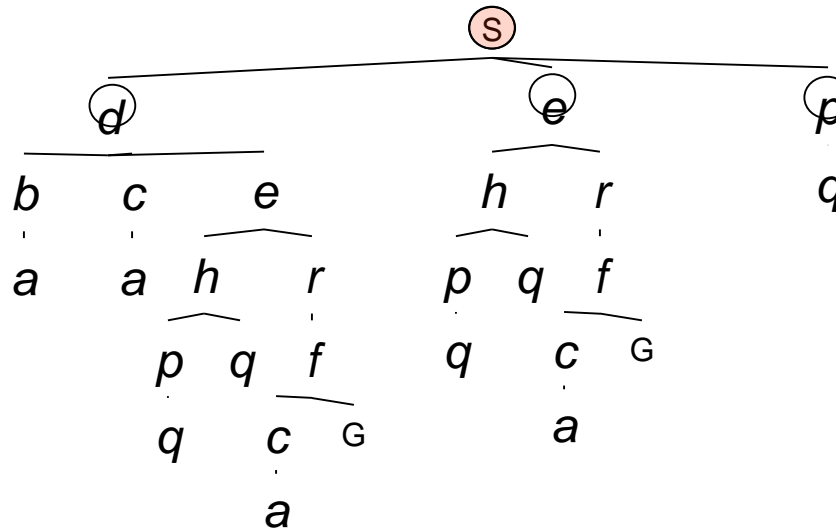
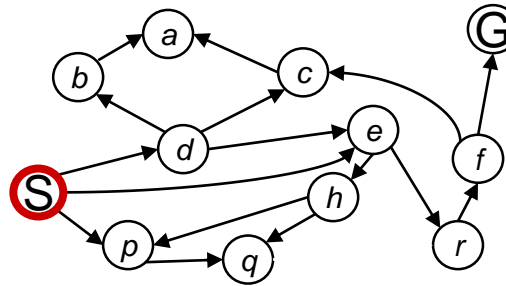


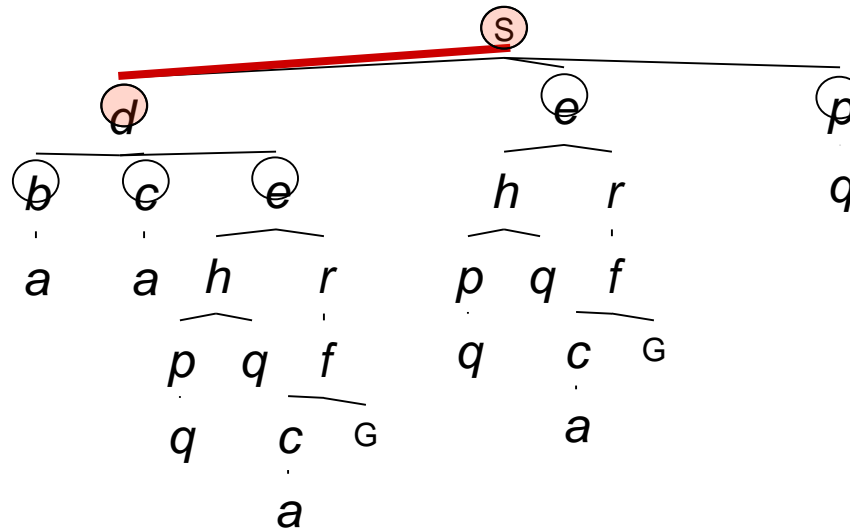


Depth-First Search

*Strategy: expand
a deepest node
first*

*Implementation:
Fringe is a LIFO
stack*

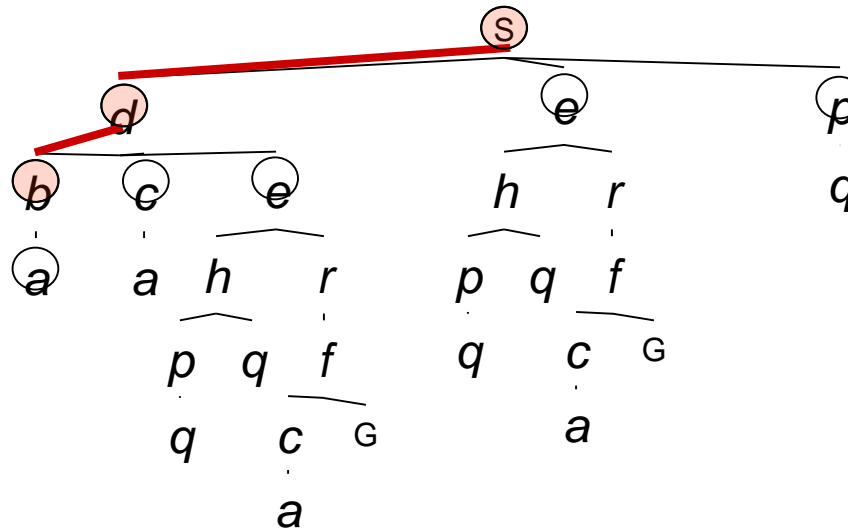
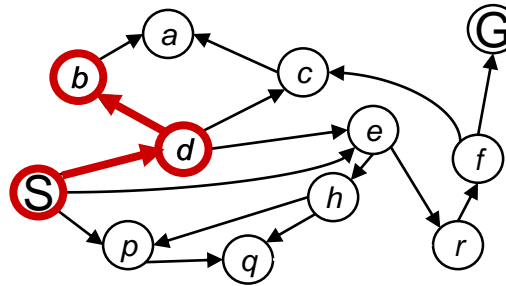




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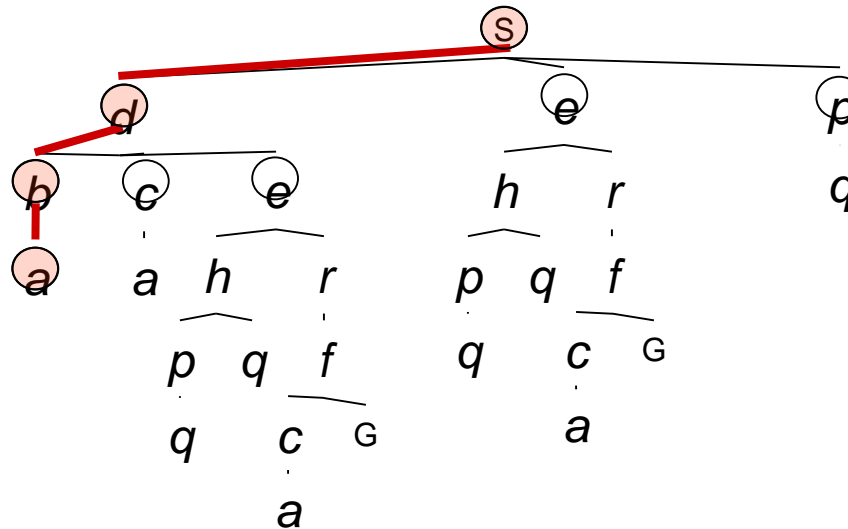
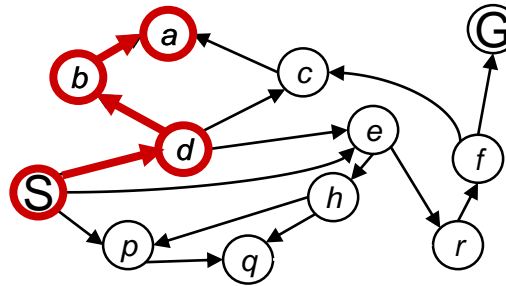
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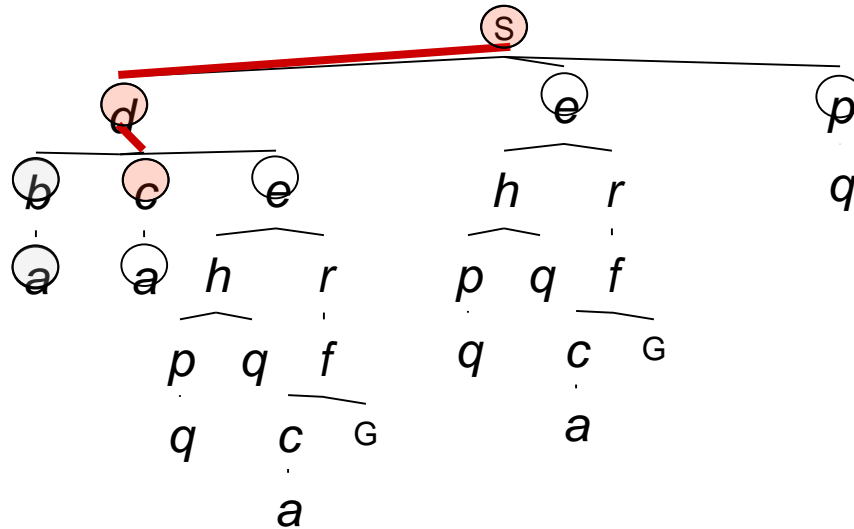
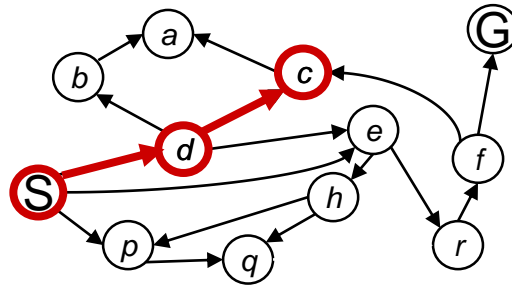
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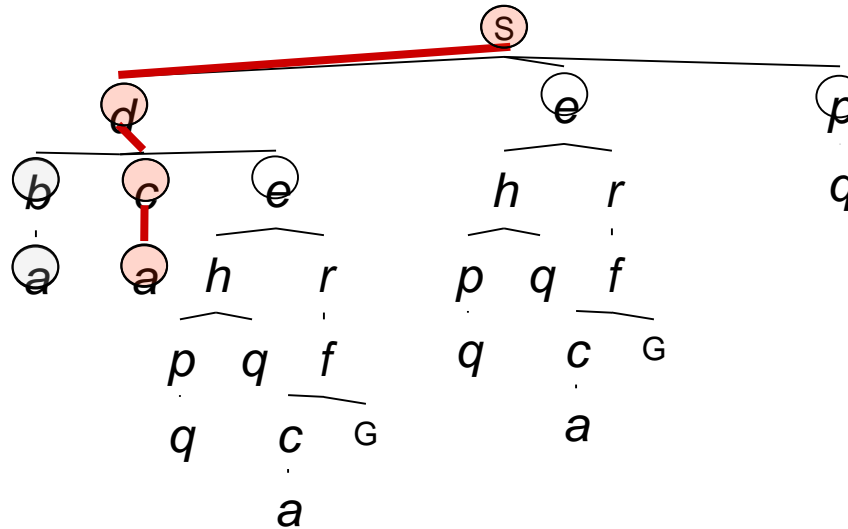
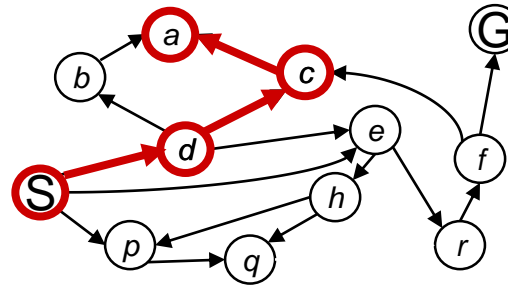
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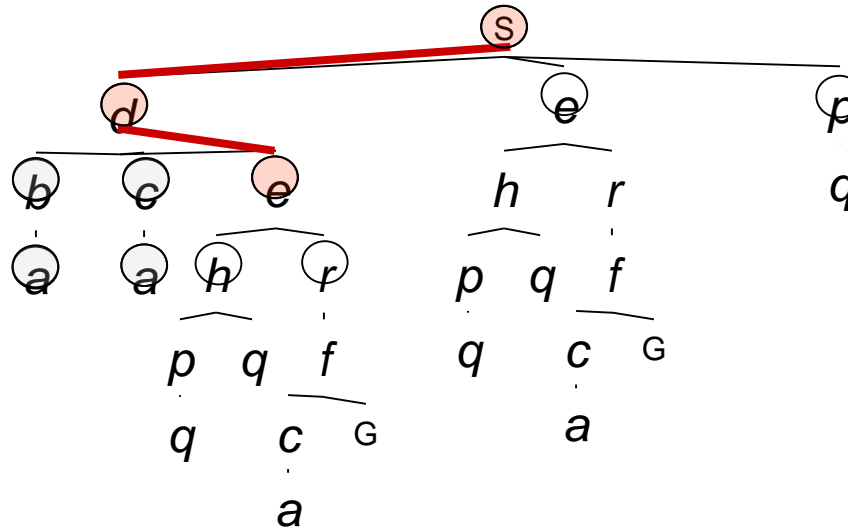
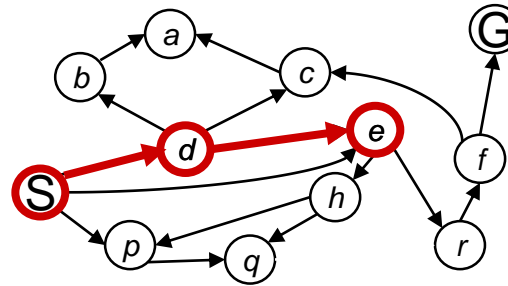
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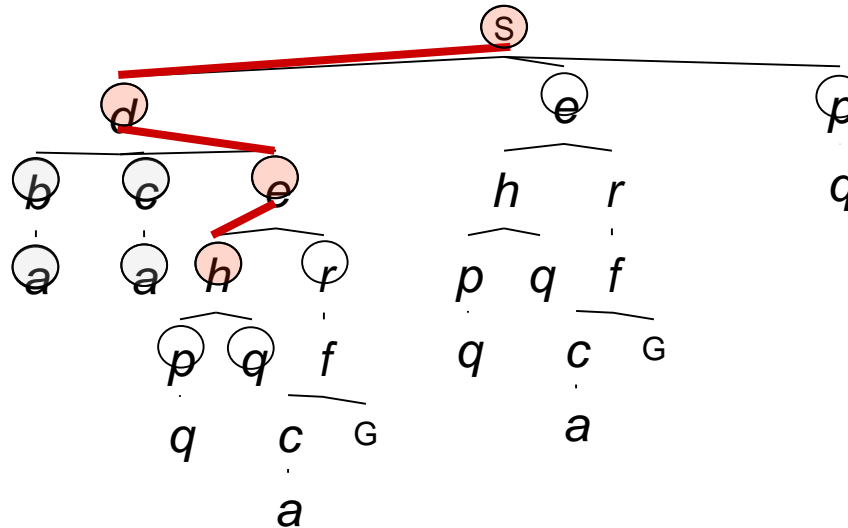
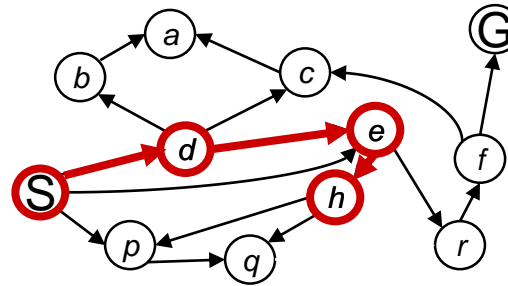
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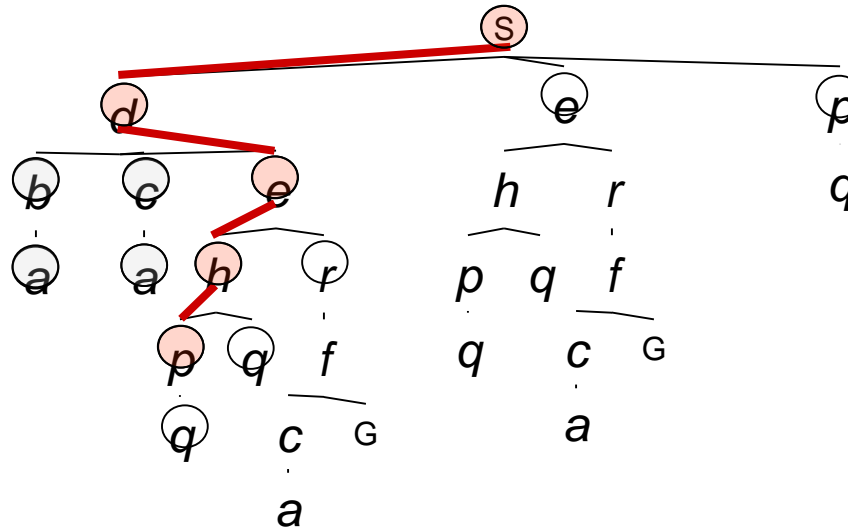
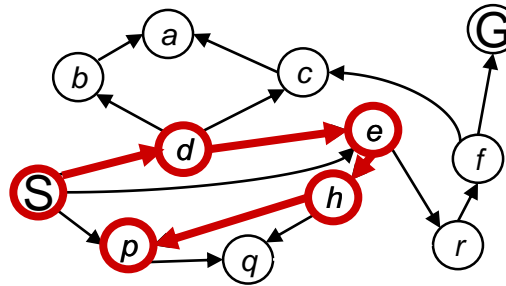
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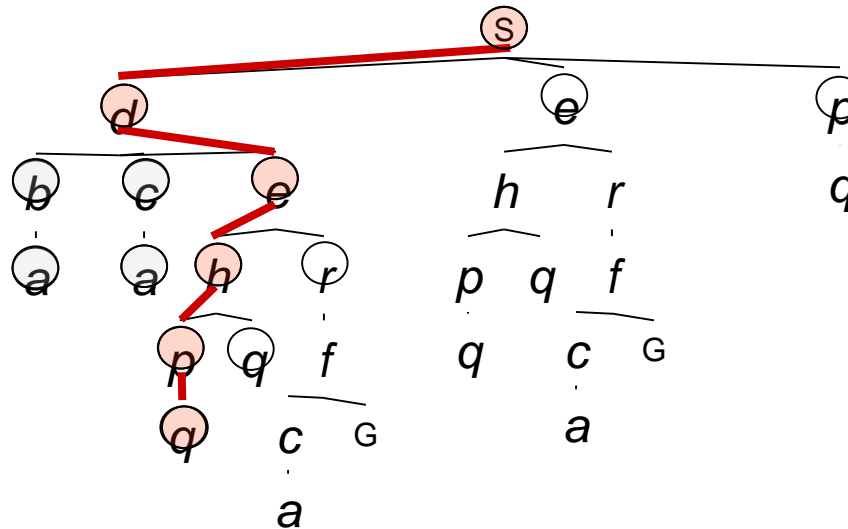
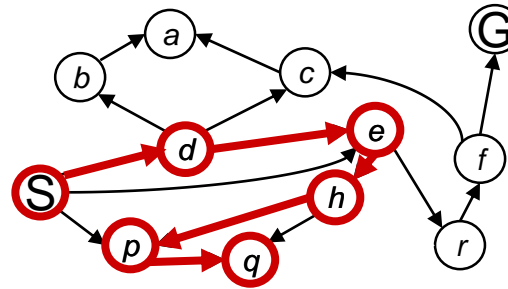
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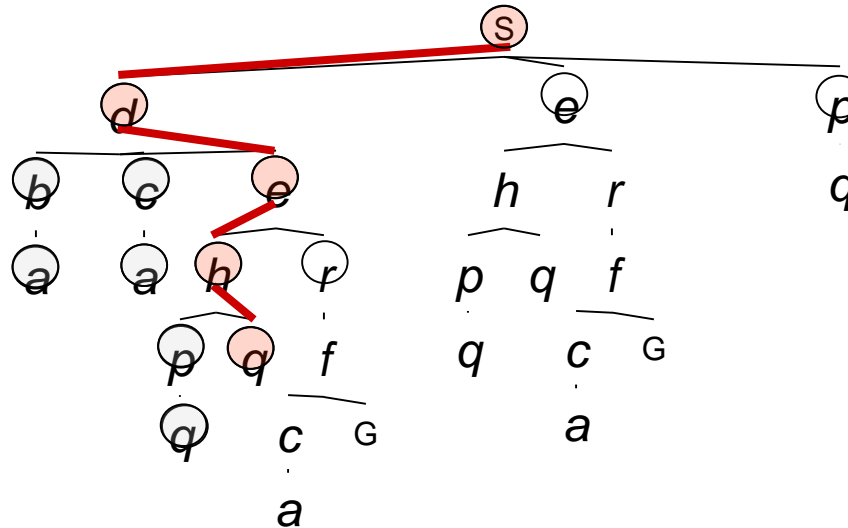
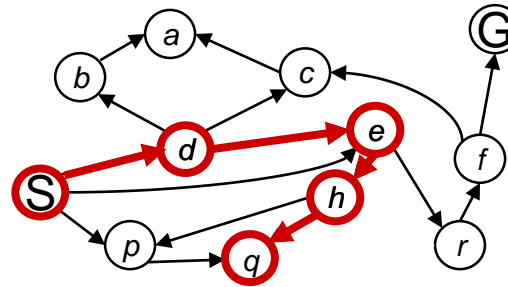
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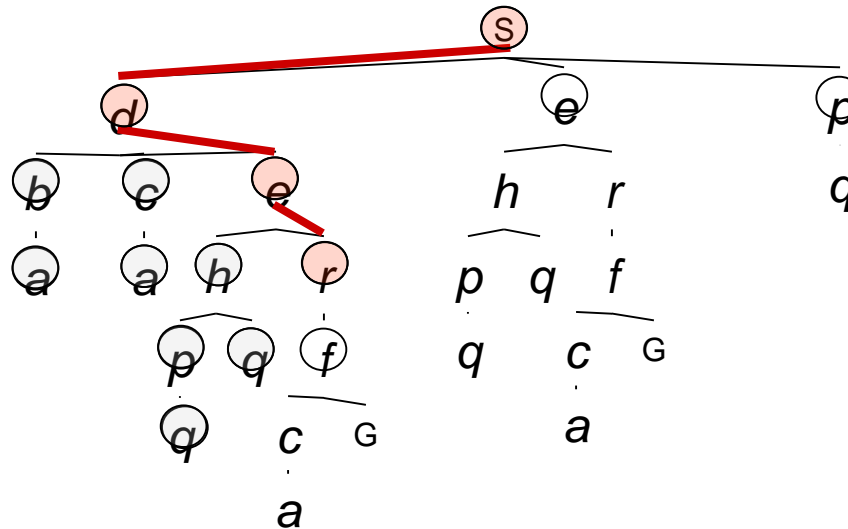
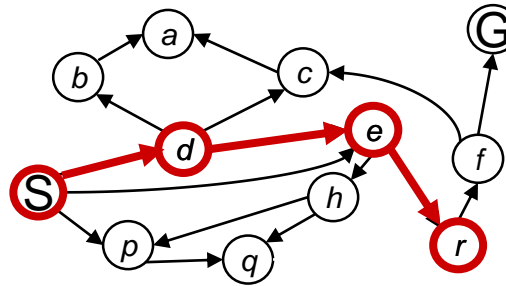
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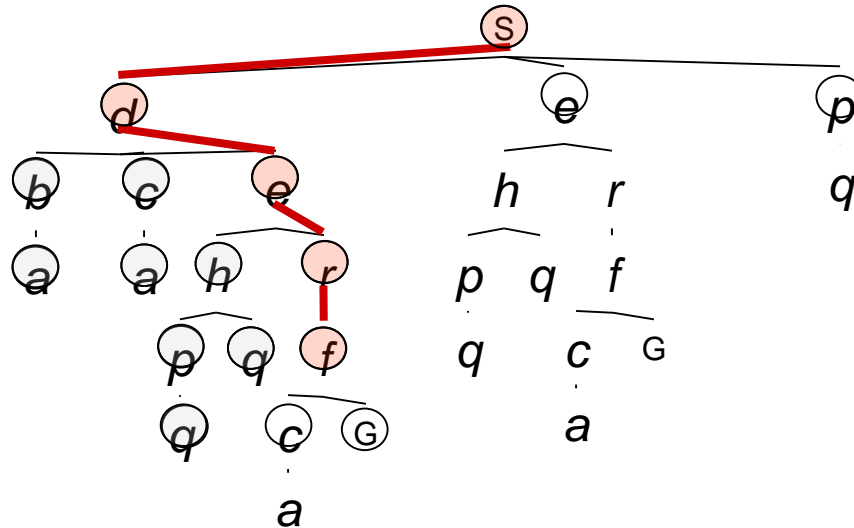
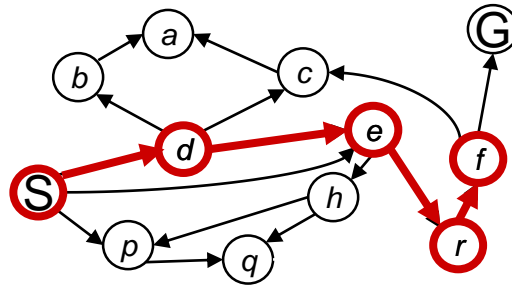
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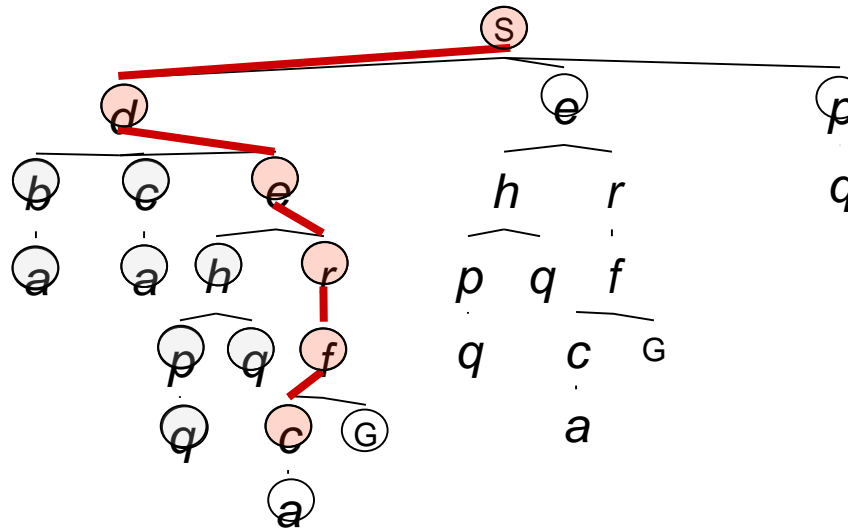
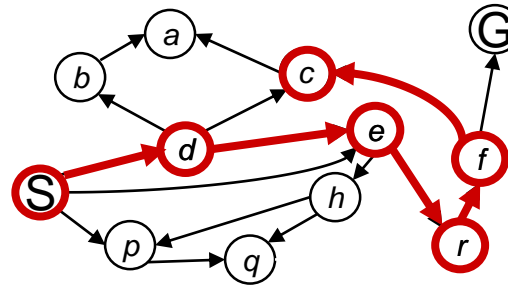
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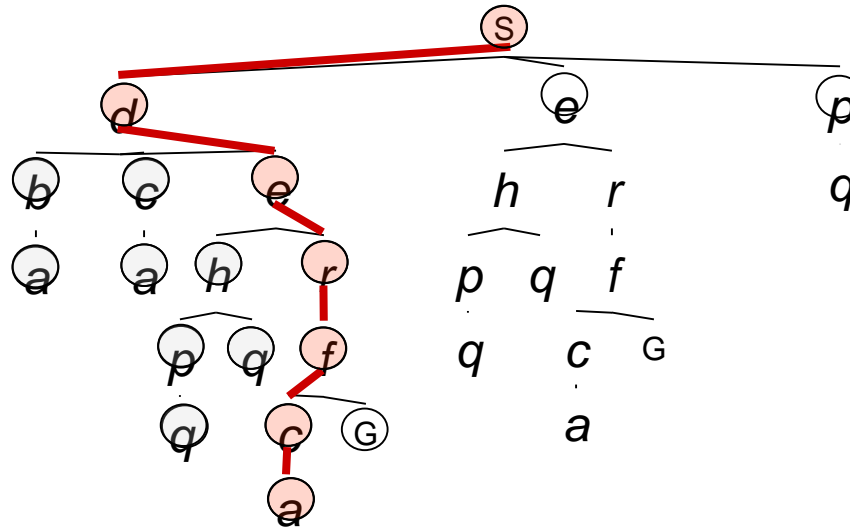


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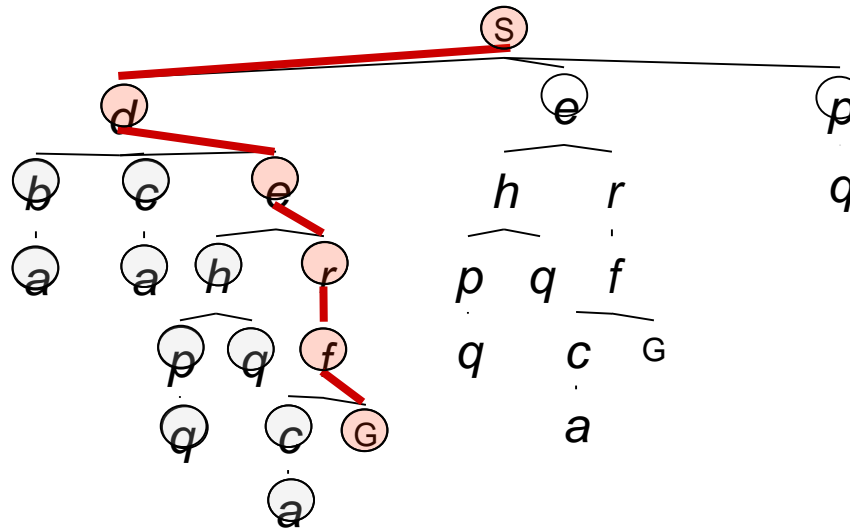
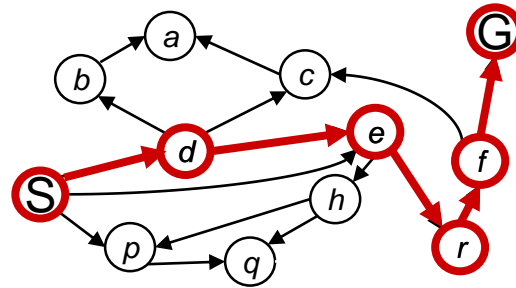




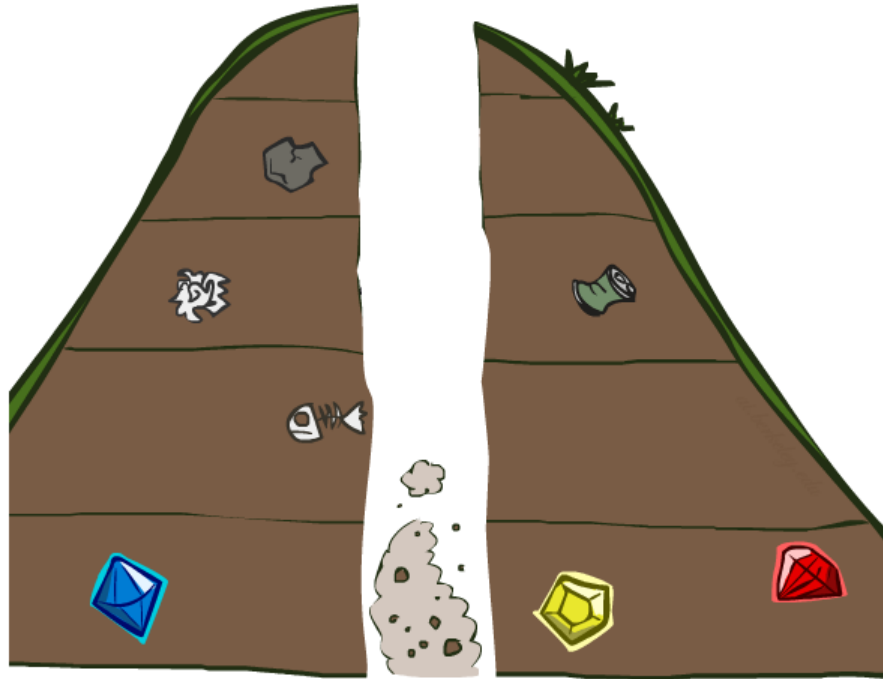
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Search Algorithm Properties



Search Algorithm Properties

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Search Algorithm Properties

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- Optimal: Guaranteed to find the least cost path?
- Time complexity?

Search Algorithm Properties

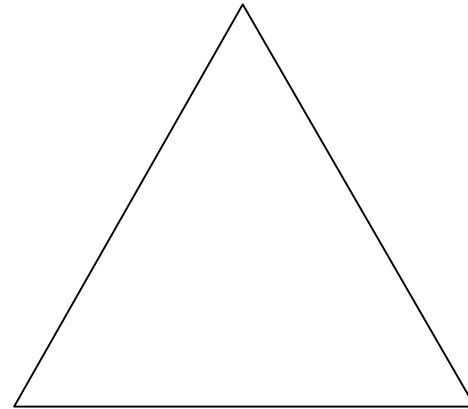
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Search Algorithm Properties

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- Cartoon of search tree:

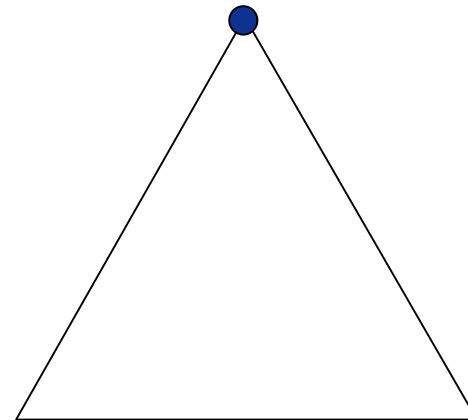
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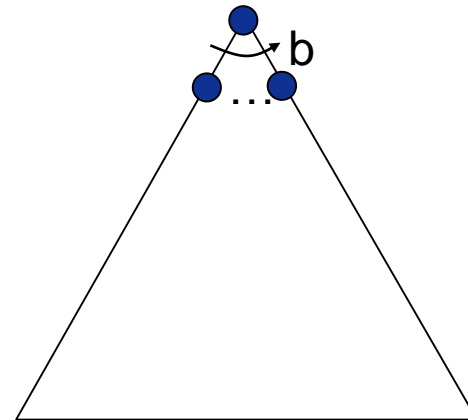
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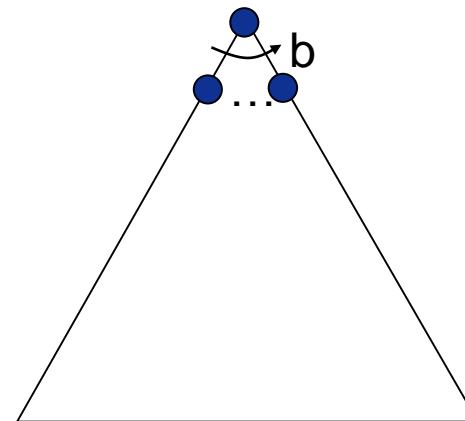
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Search Algorithm Properties

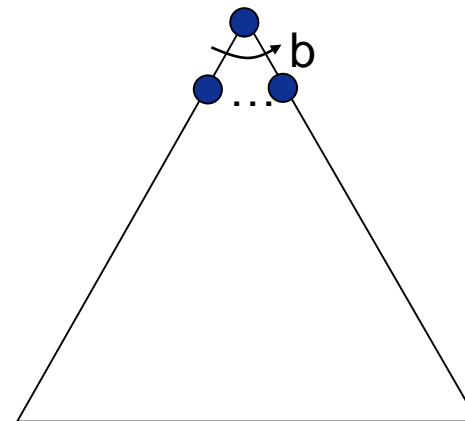
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1 node

Search Algorithm Properties

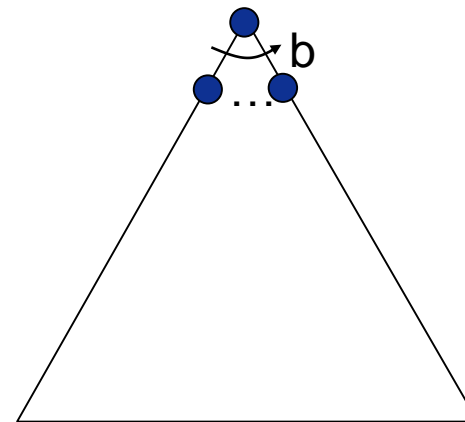
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1 node
 b
nodes

Search Algorithm Properties

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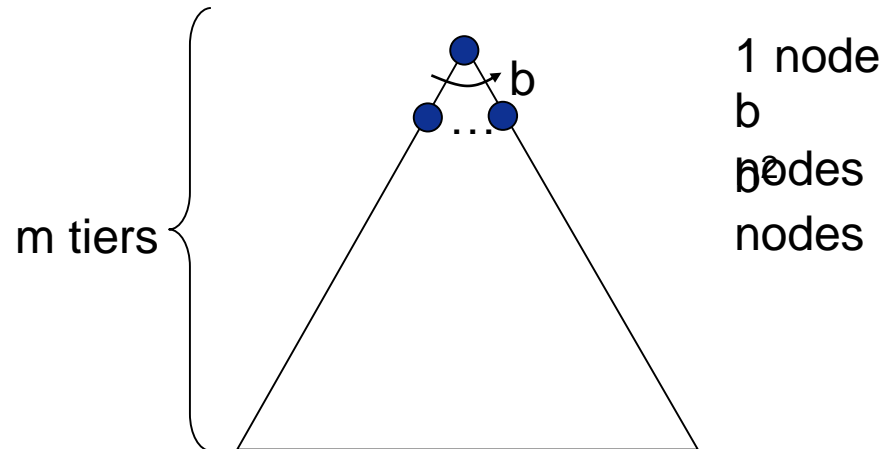
1 node
 b
 b^2 nodes
 b^3 nodes

Search Algorithm Properties

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- Space complexity?

- Cartoon of search tree:

- b is the branching factor
- m is the maximum depth

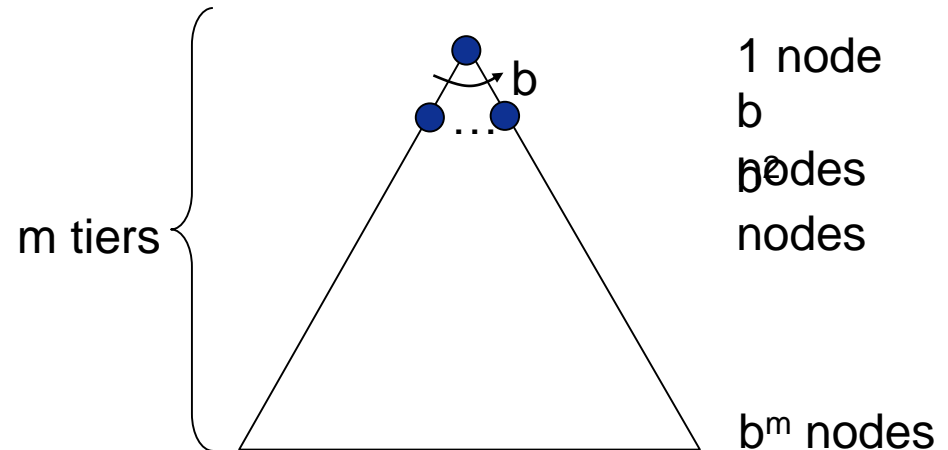


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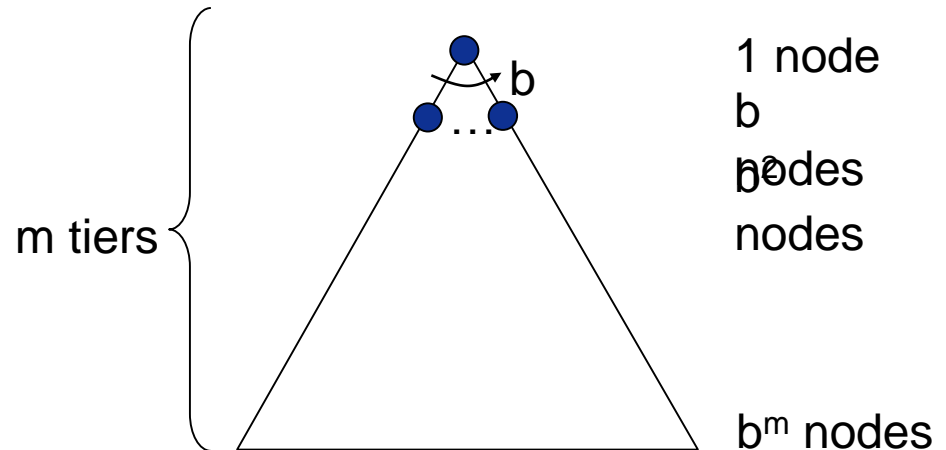
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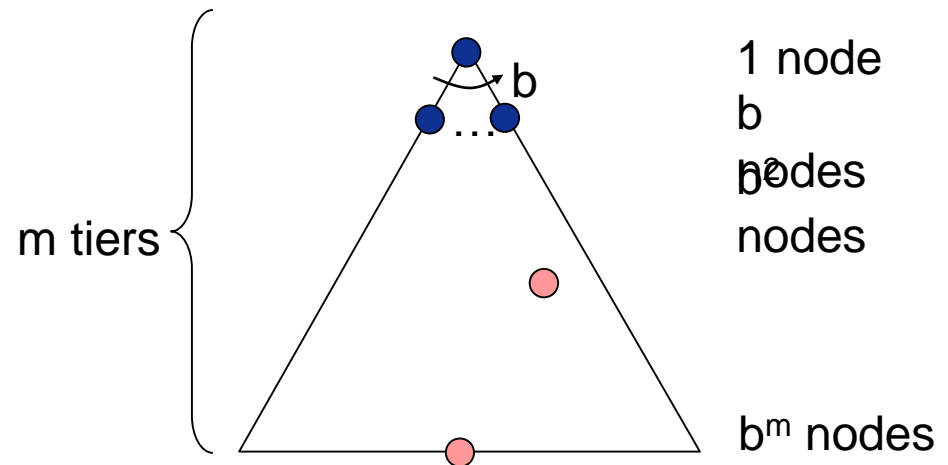
- Cartoon of search tree:
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 - solutions at various depths



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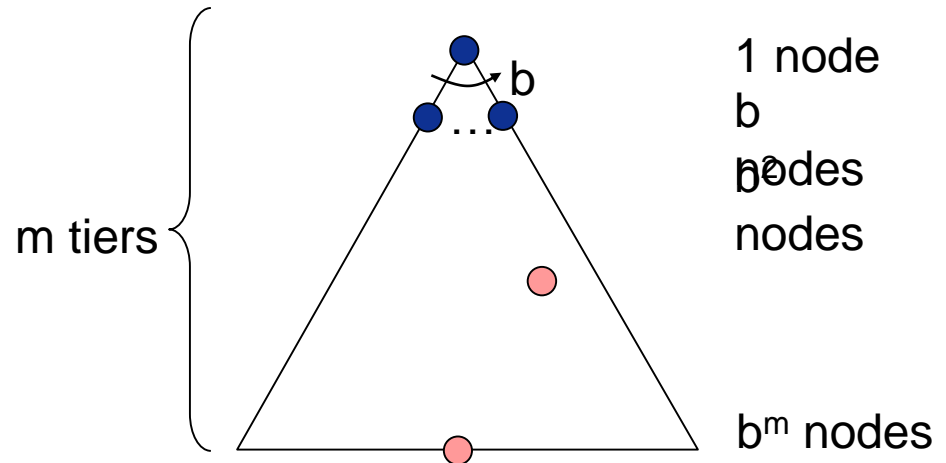
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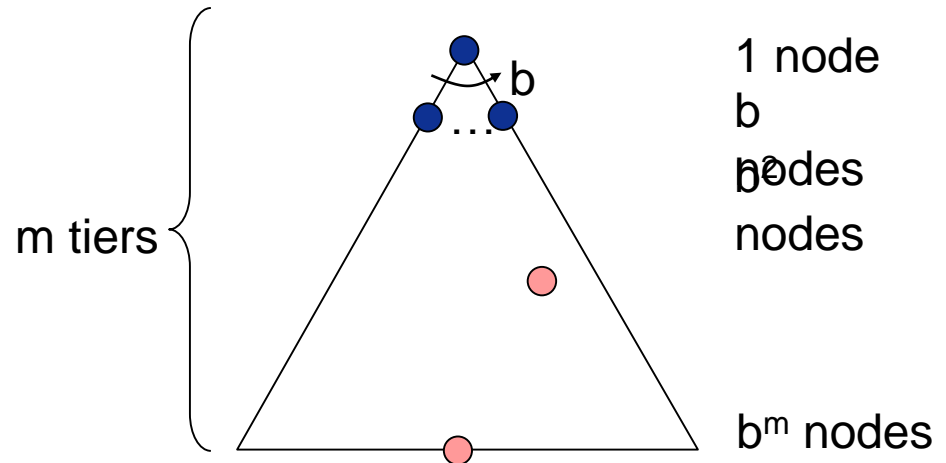


- Number of nodes in entire tree?

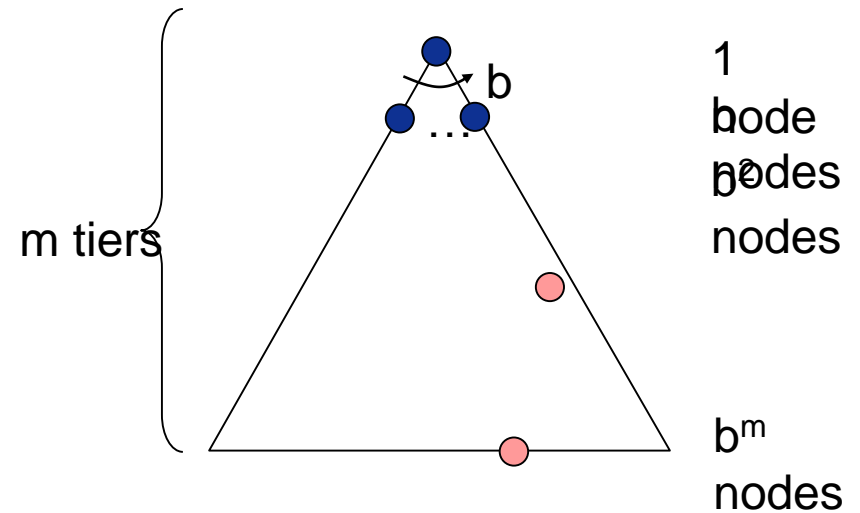
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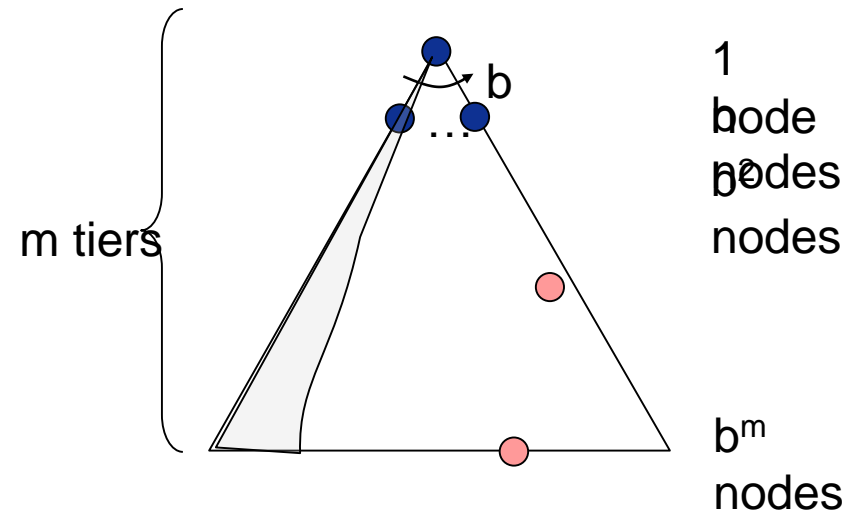


- Number of nodes in entire tree?
 - $1 + b + b^2 + \dots + b^m = O(b^m)$



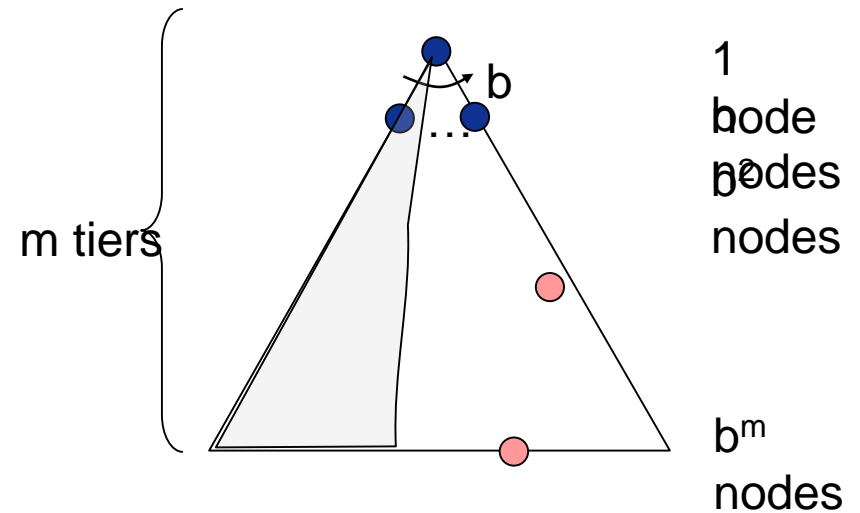
Depth-First Search (DFS) Properties

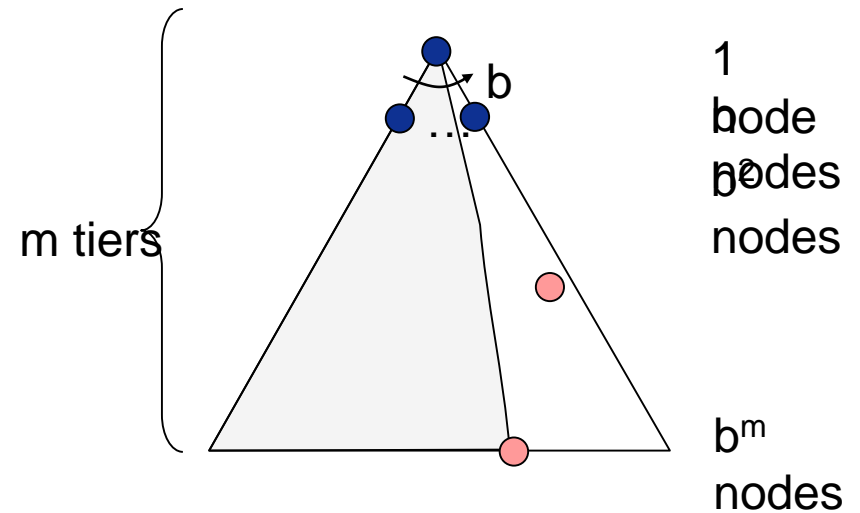
- What nodes DFS expand?



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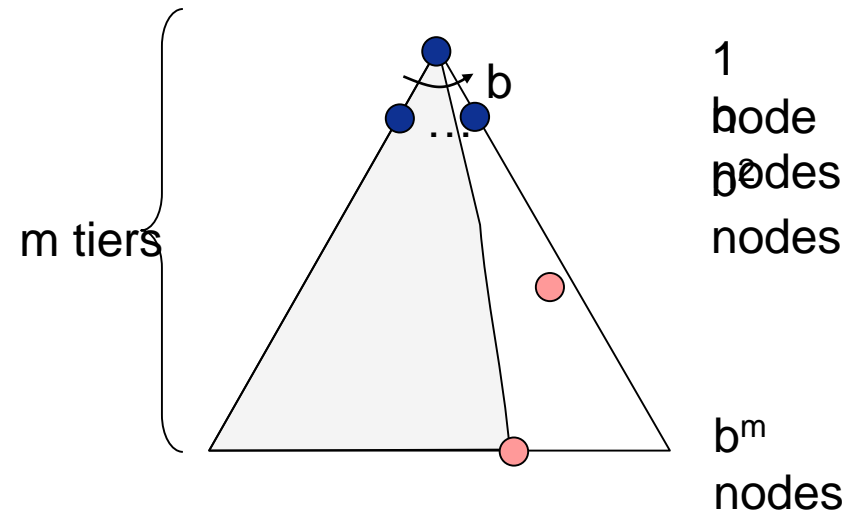
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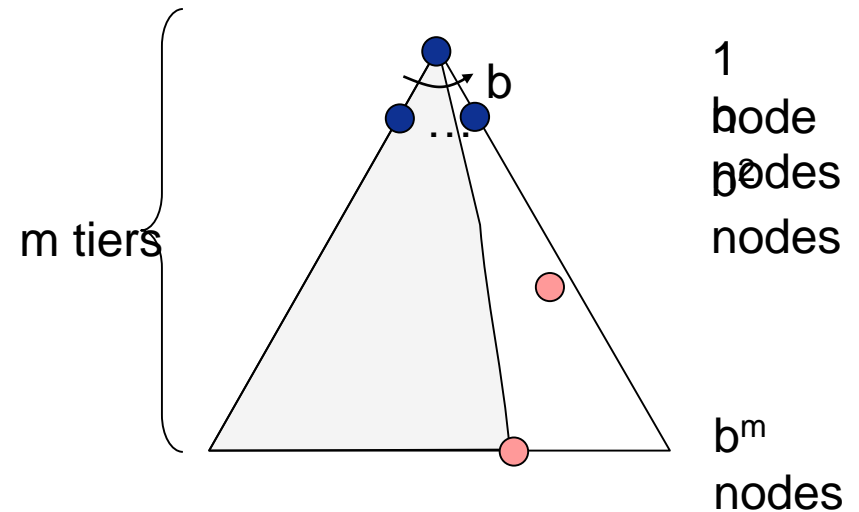
Depth-First Search (DFS) Properties

- What nodes DFS expand?
 - Some left prefix of the tree.



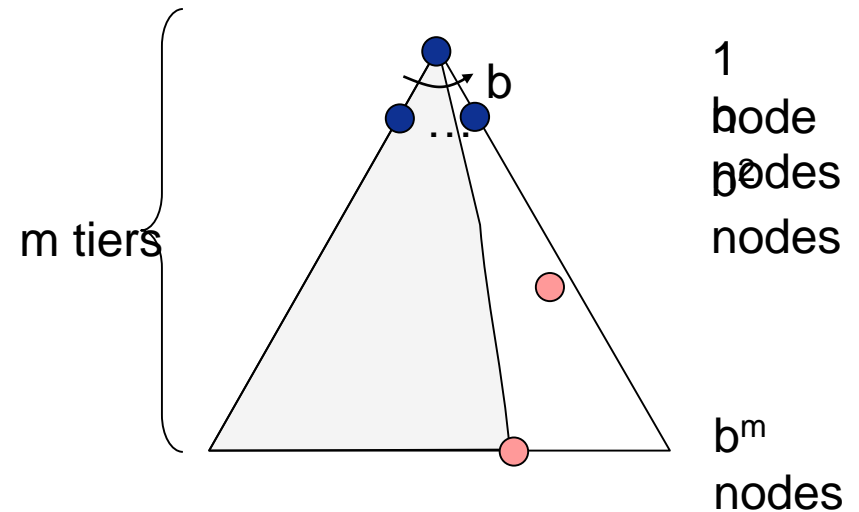
Depth-First Search (DFS) Properties

- What nodes DFS expand?
 - Some left prefix of the tree.
 - Could process the whole tree!



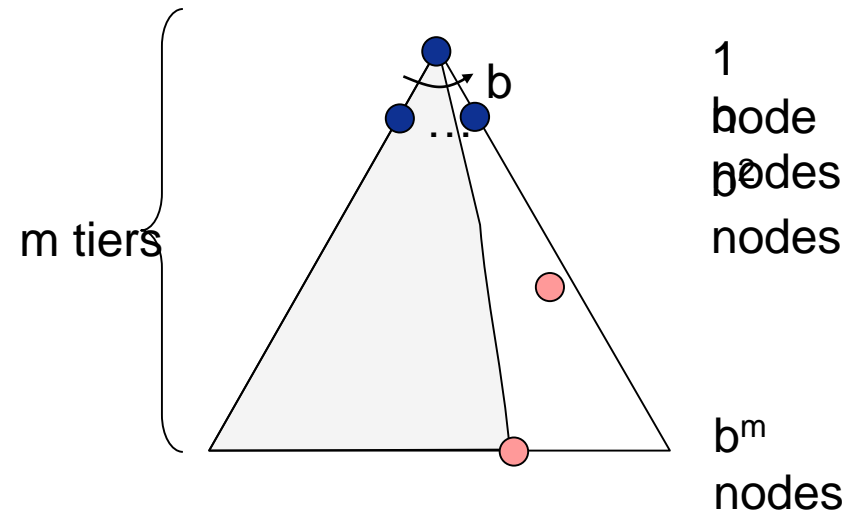
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- What nodes DFS expand?
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 - If m is finite, takes time $O(b^m)$



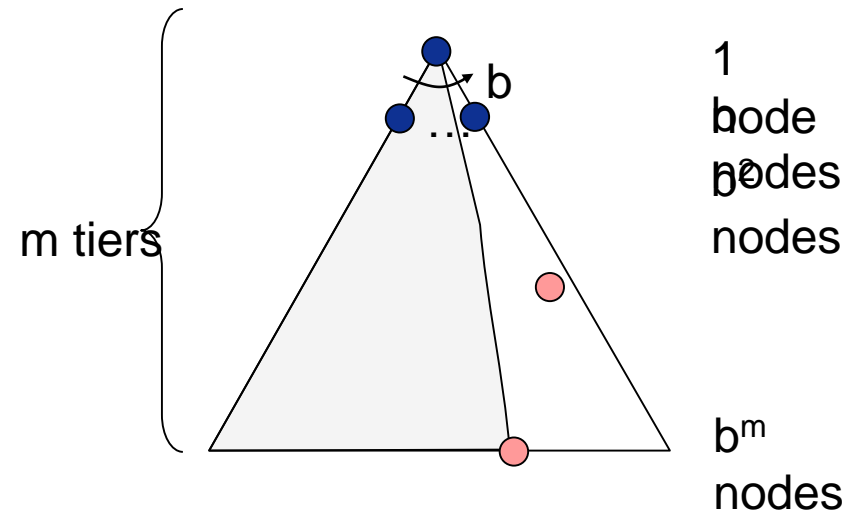
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- What nodes DFS expand?
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 - Could process the whole tree!
 - If m is finite, takes time $O(b^m)$
- How much space does the fringe take?



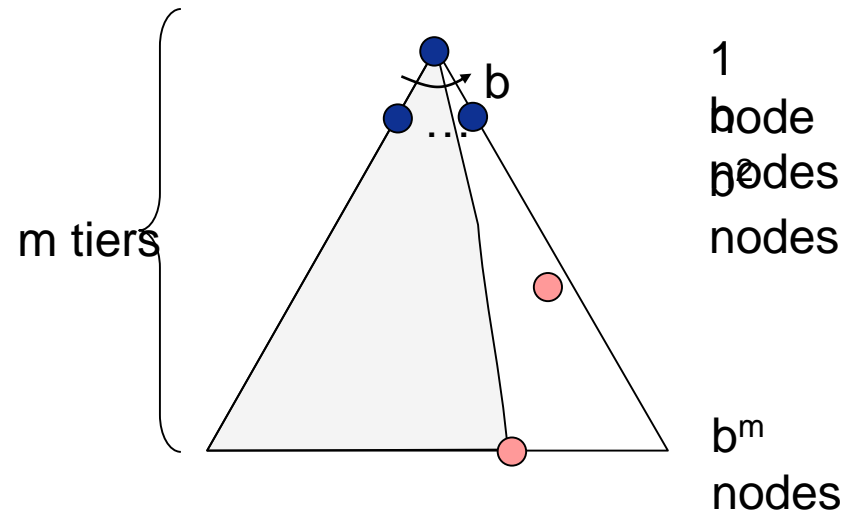
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 - Could process the whole tree!
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 - Only has siblings on path to root, so $O(bm)$



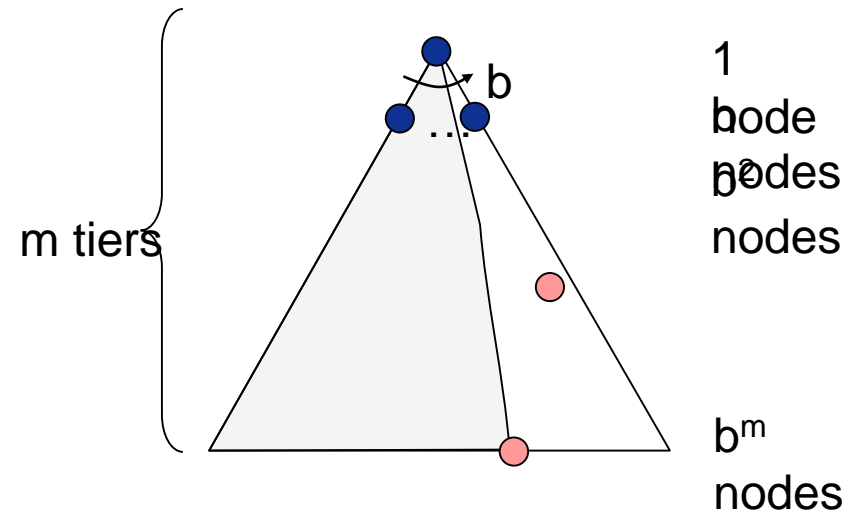
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- What nodes DFS expand?
 - Some left prefix of the tree.
 - Could process the whole tree!
 - If m is finite, takes time $O(b^m)$
- How much space does the fringe take?
 - Only has siblings on path to root, so $O(bm)$
- Is it complete?



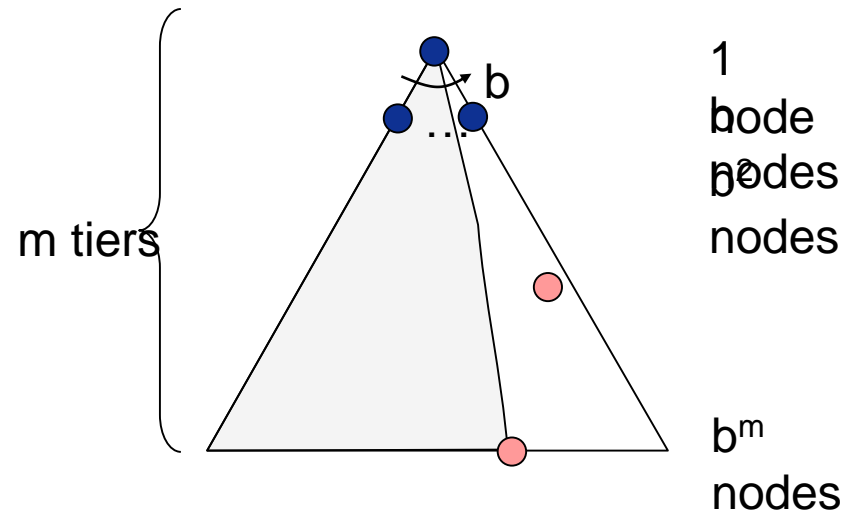
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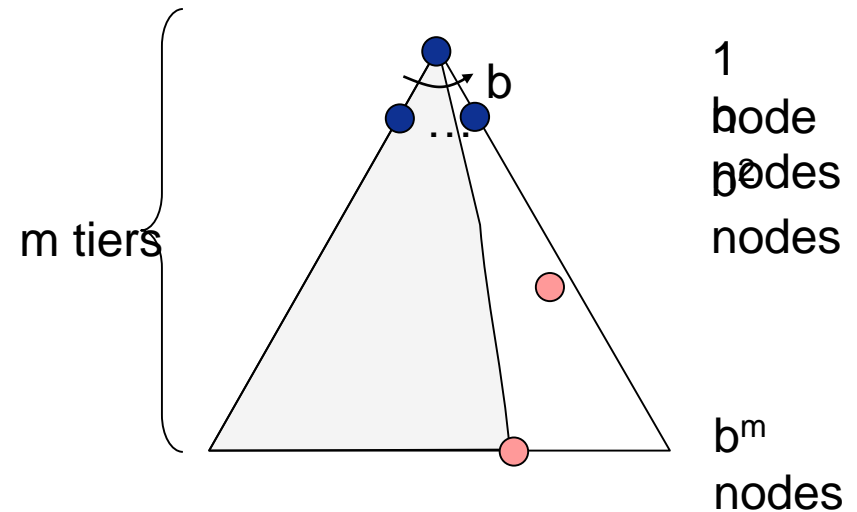
Depth-First Search (DFS) Properties

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 - Some left prefix of the tree.
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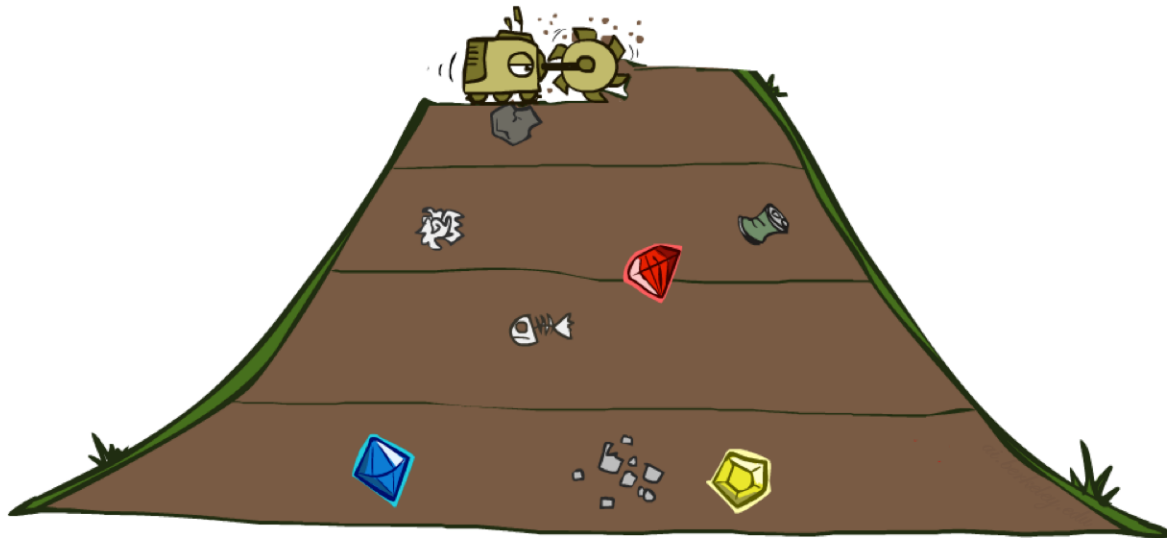


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 - No, it finds the “leftmost” solution, regardless of depth or cost



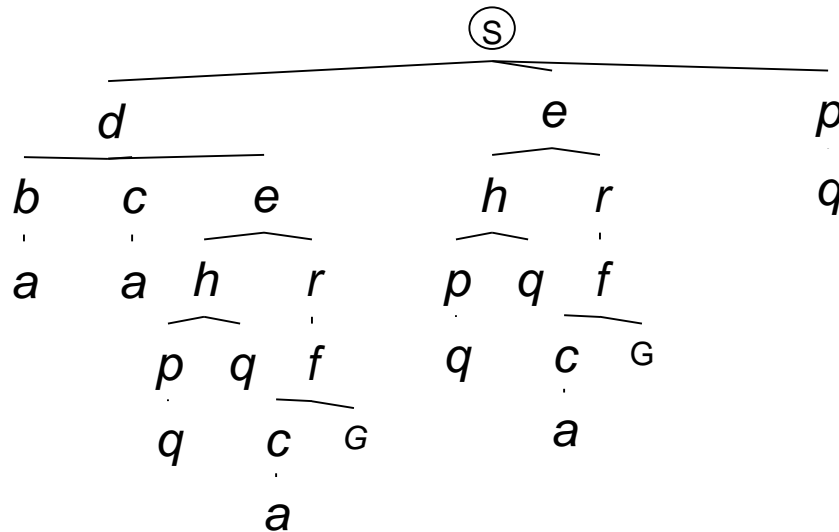
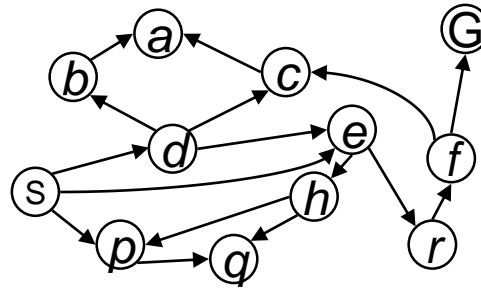
Breadth-First Search



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*Strategy: expand
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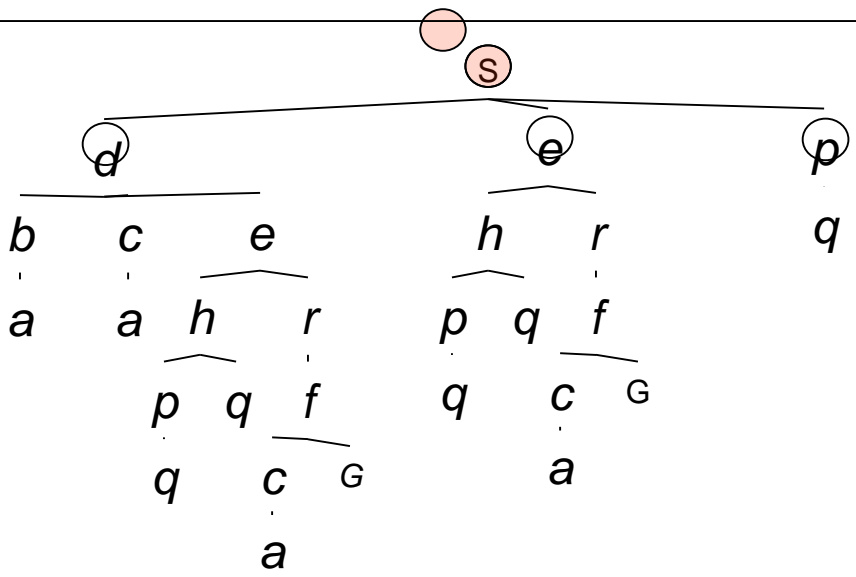
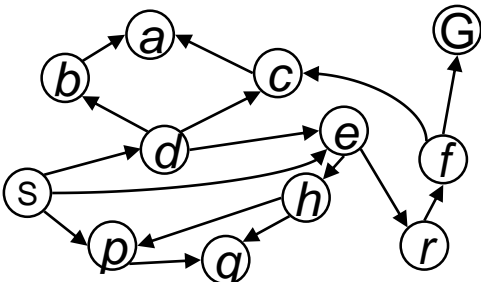
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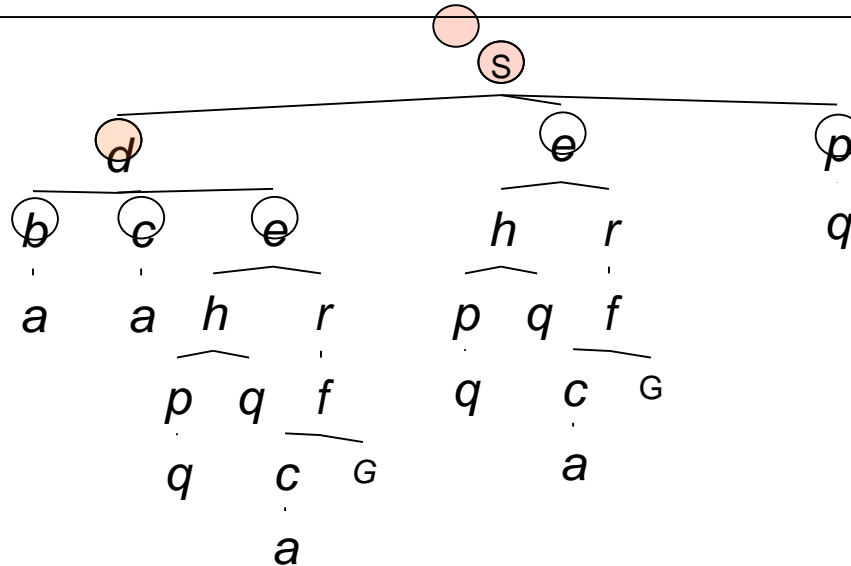
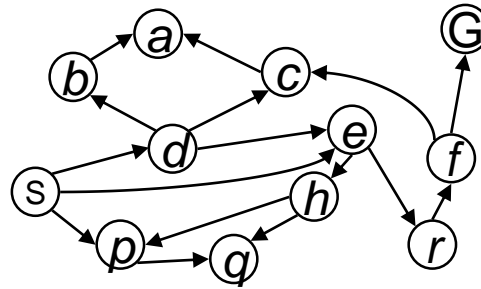
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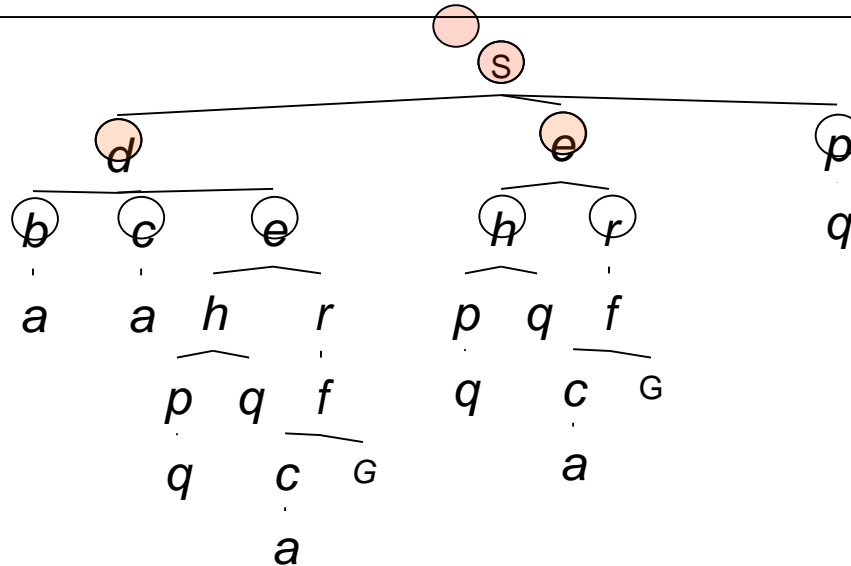
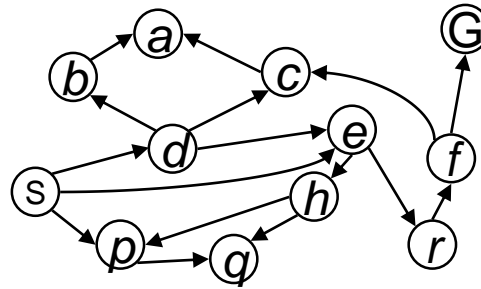
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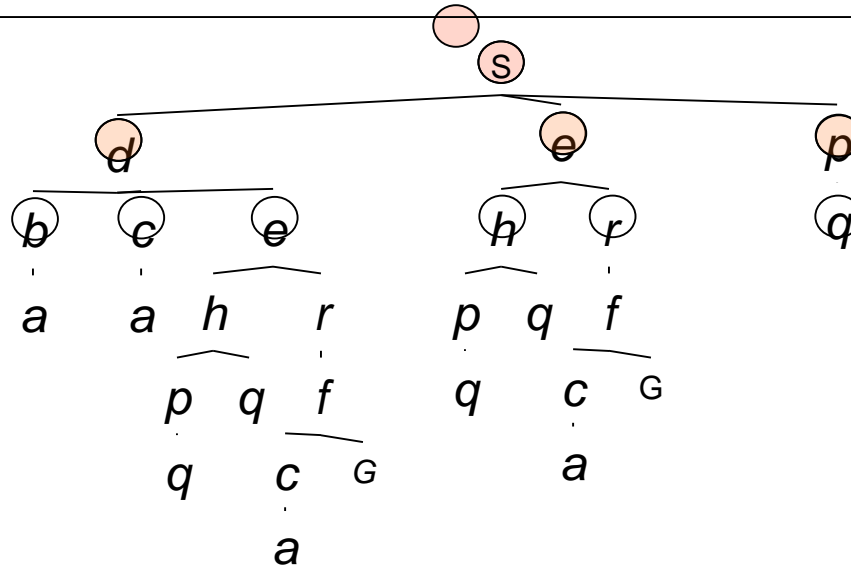
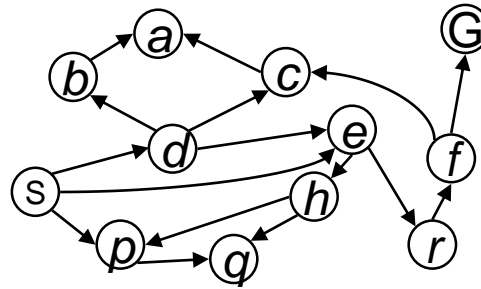
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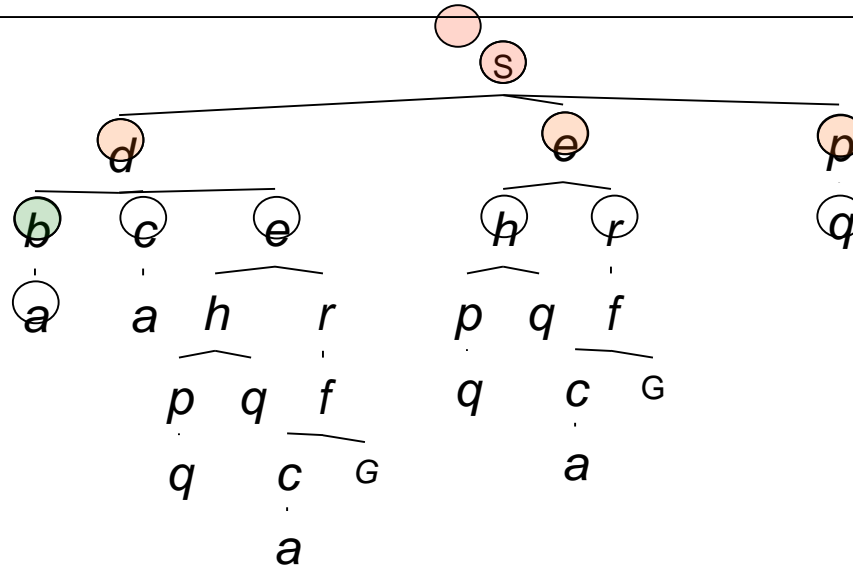
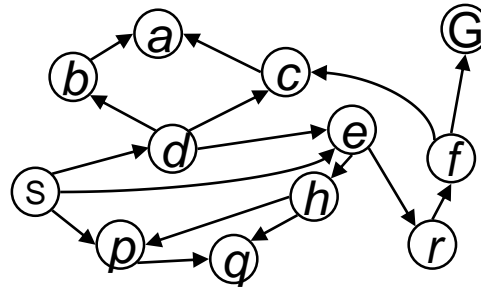
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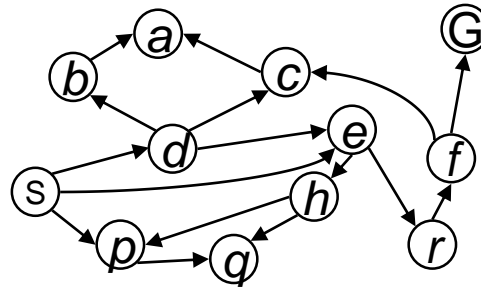
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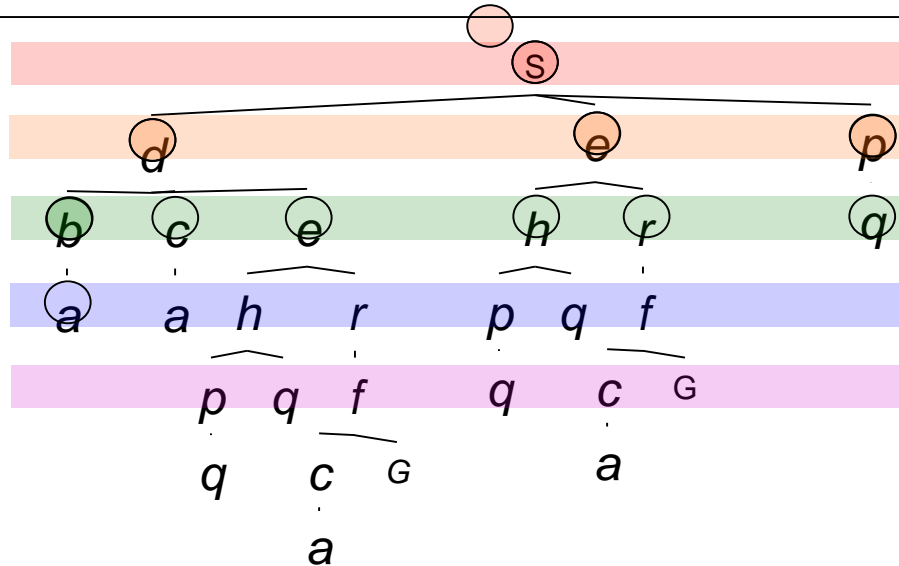
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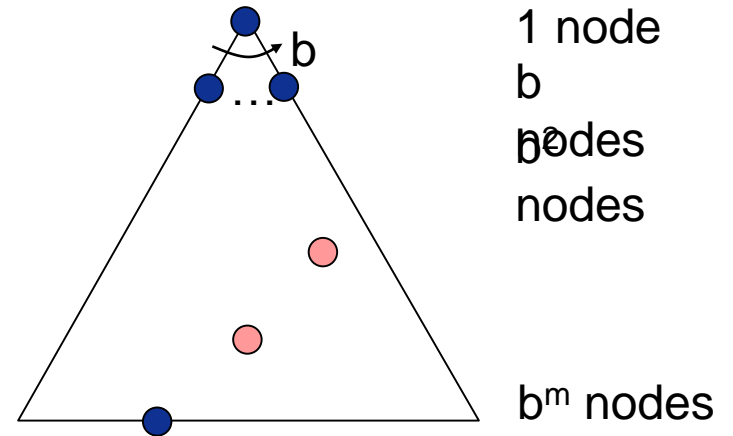


Search
Tiers



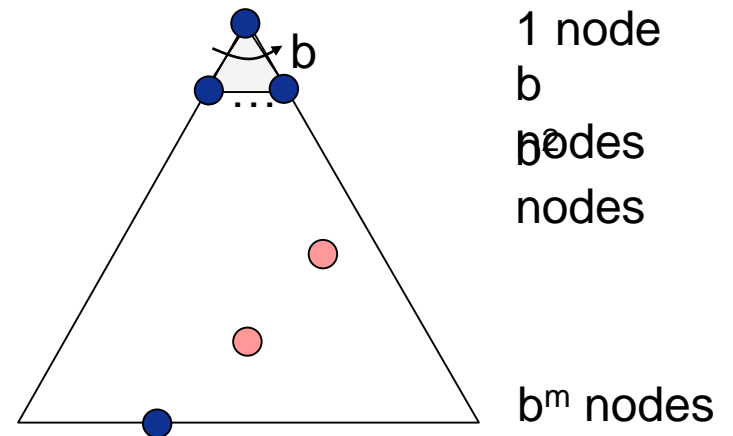
Breadth-First Search (BFS) Properties

- What nodes does BFS expand?



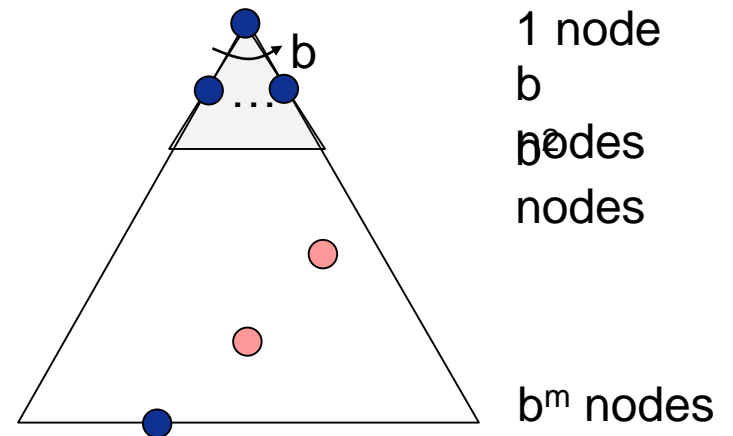
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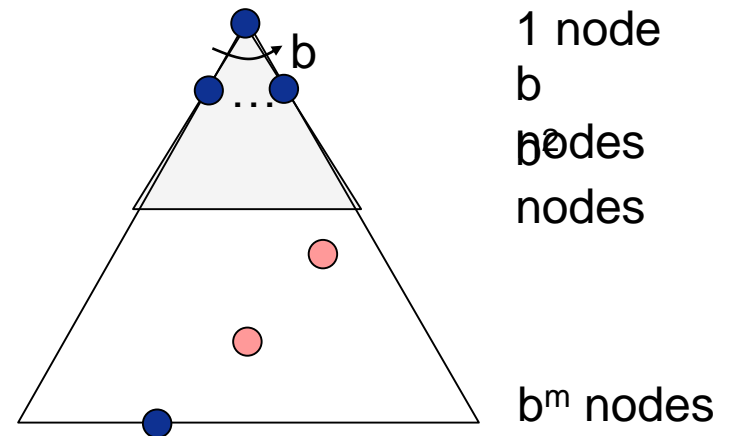
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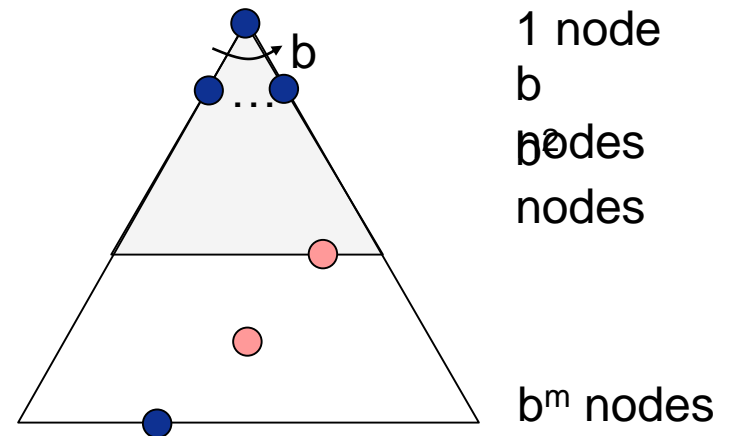
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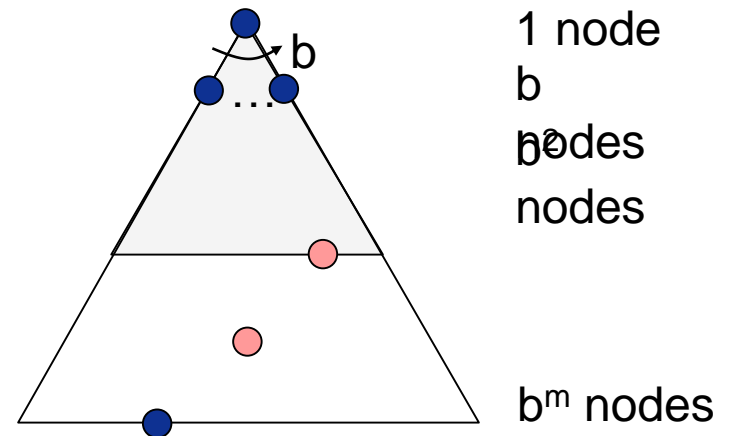
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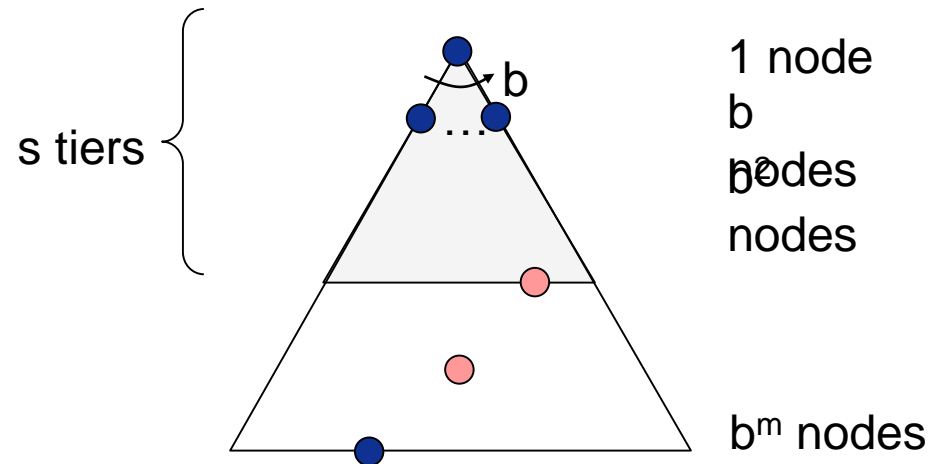
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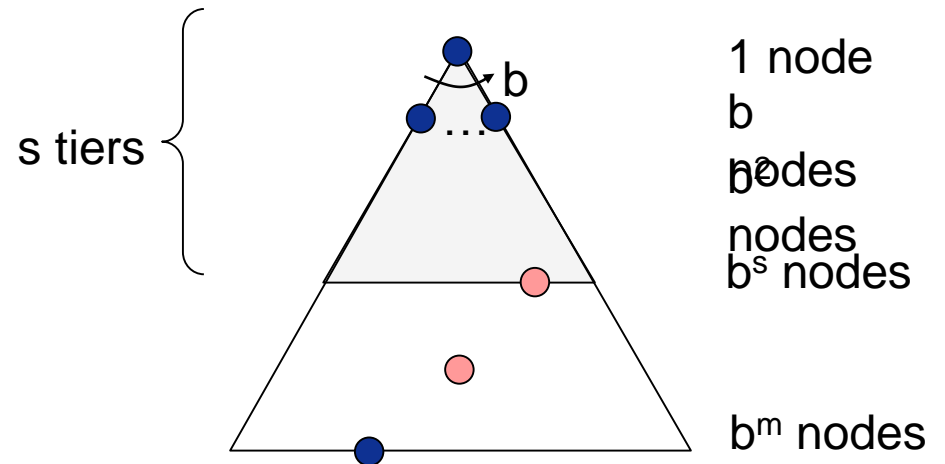
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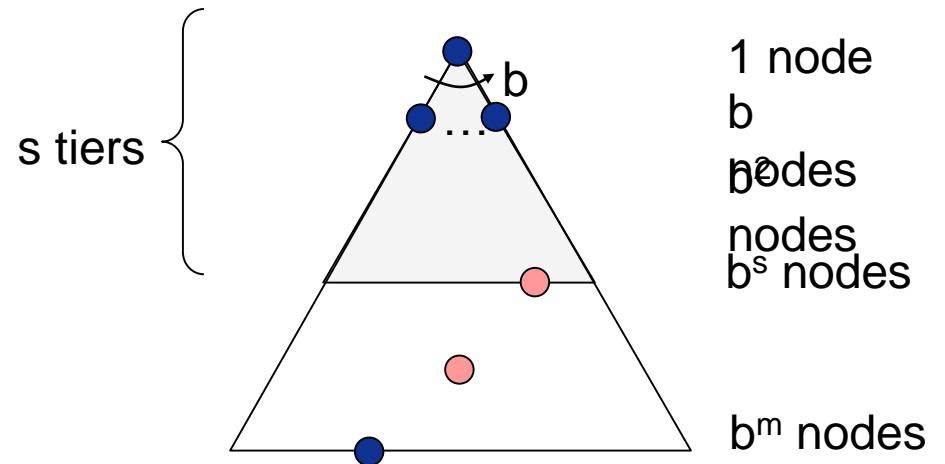
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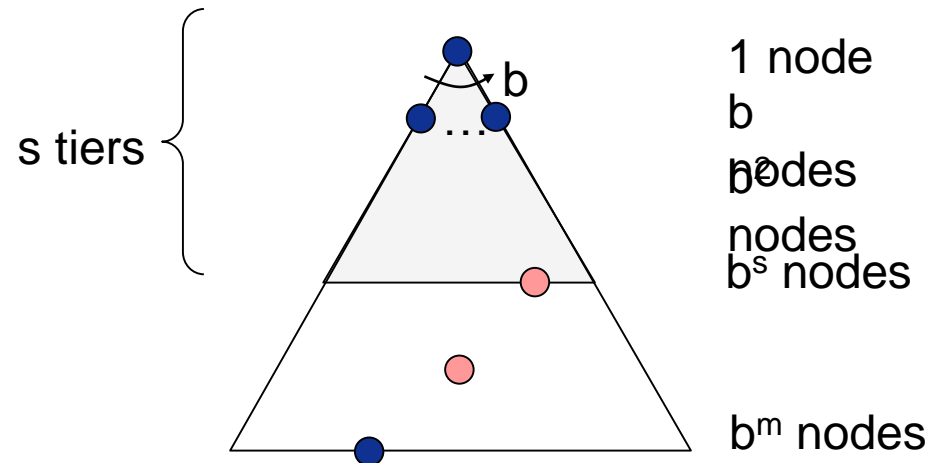


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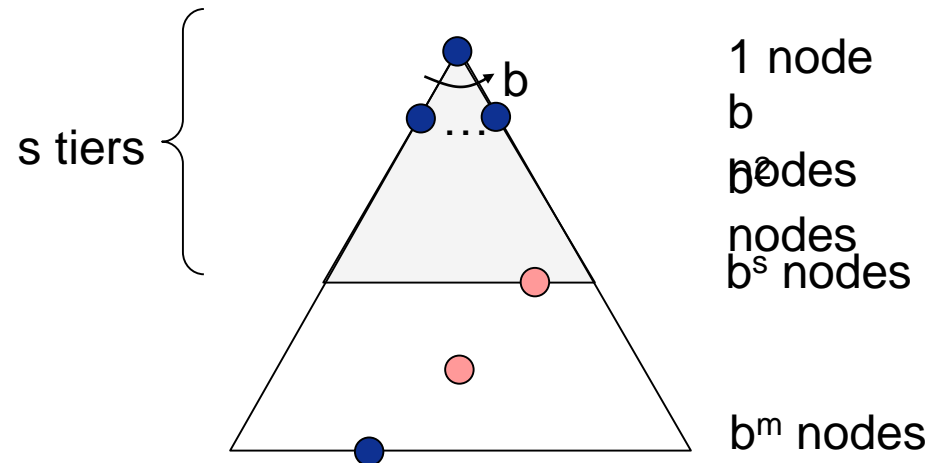
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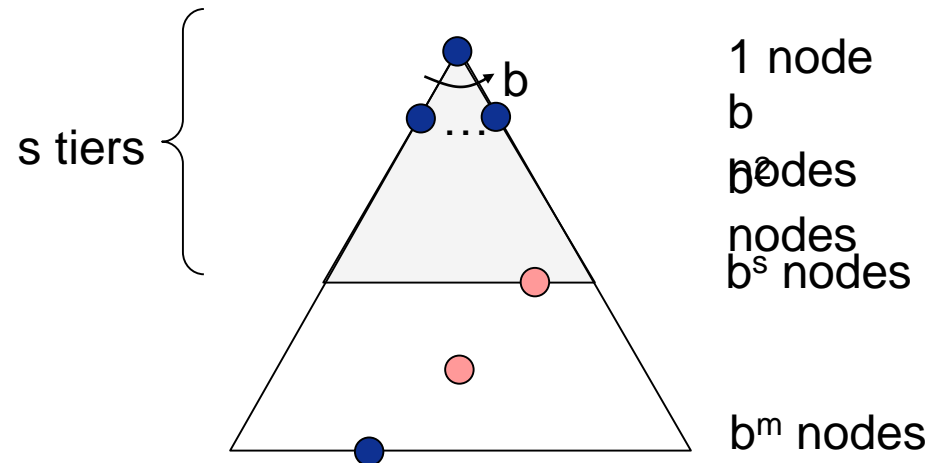
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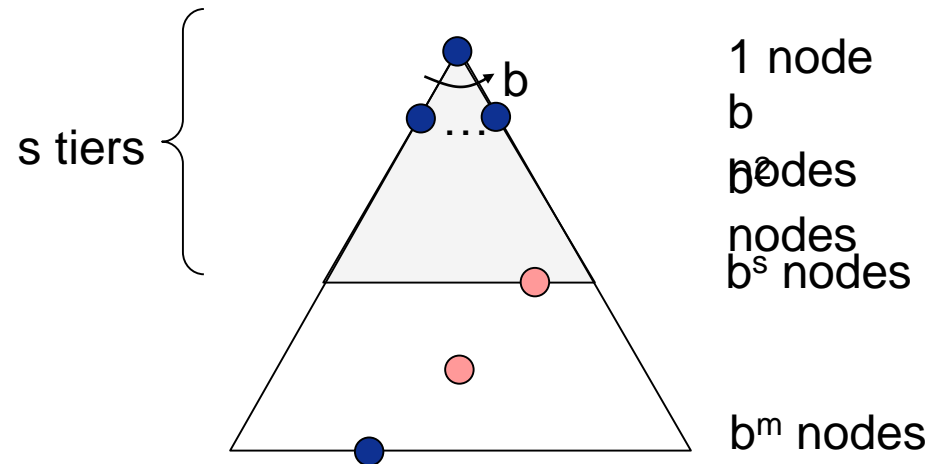
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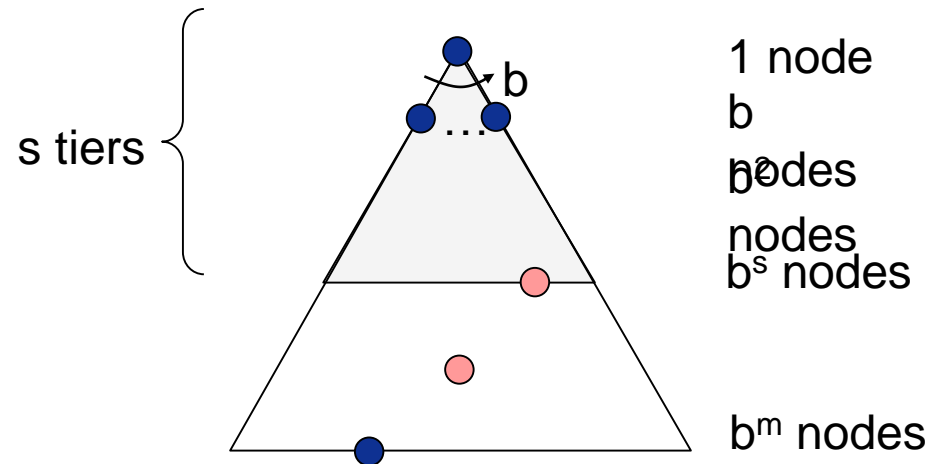
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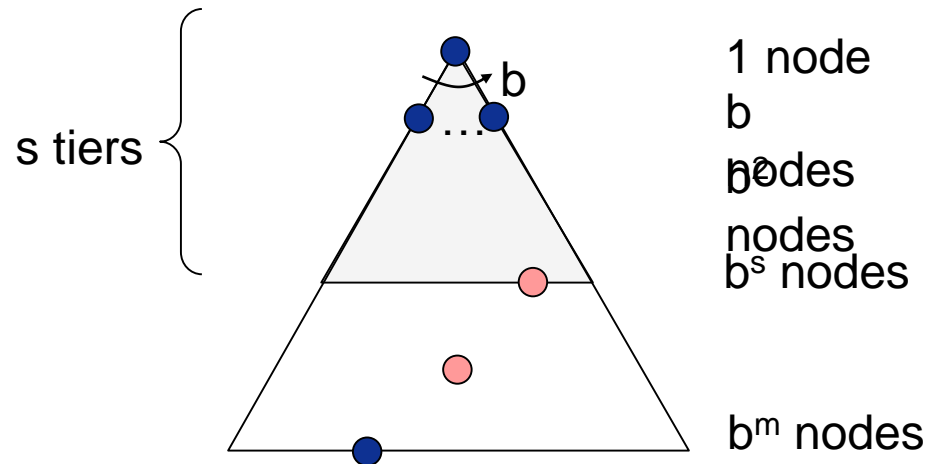
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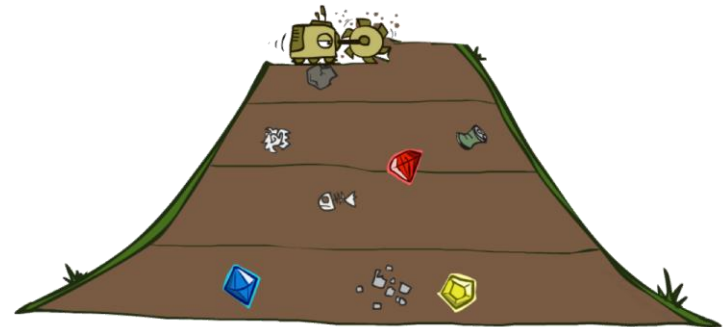
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Is it optimal?

- Only if costs are all 1 (more on costs later)



Quiz: DFS vs BFS

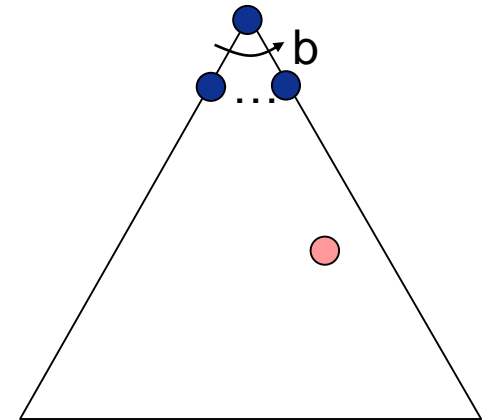


Quiz: DFS vs BFS

- When will BFS outperform DFS?
- When will DFS outperform BFS?

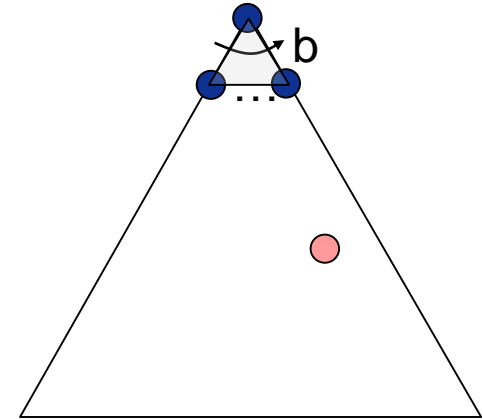
Iterative Deepening

- Idea: get DFS's space advantage with BFS's time / shallow-solution advantages



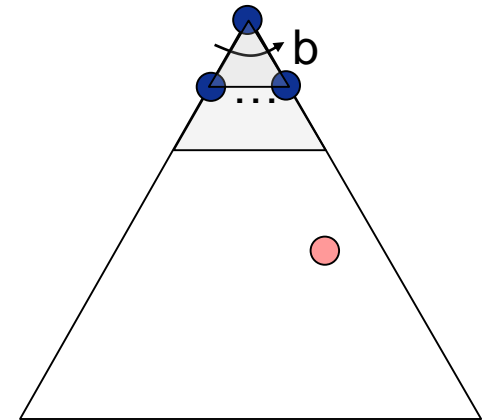
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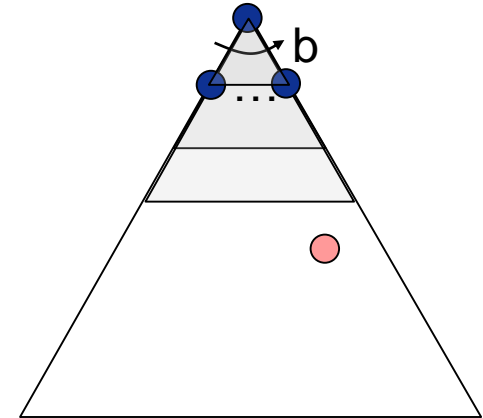
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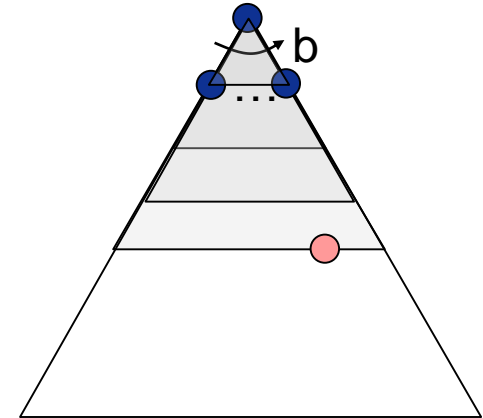
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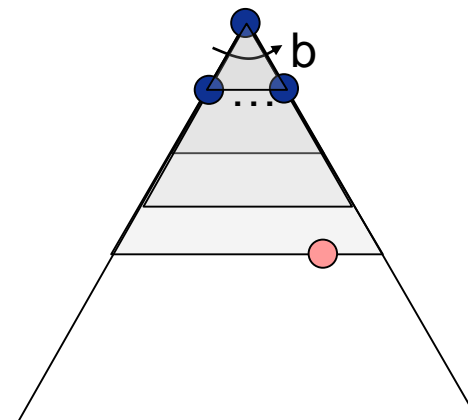
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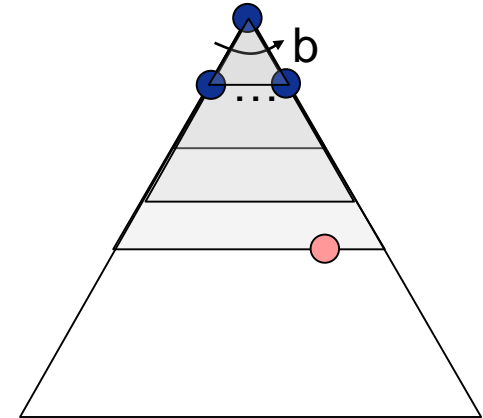
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- Isn't that wastefully redundant?



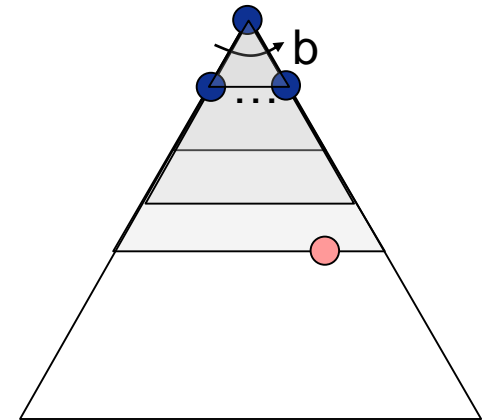
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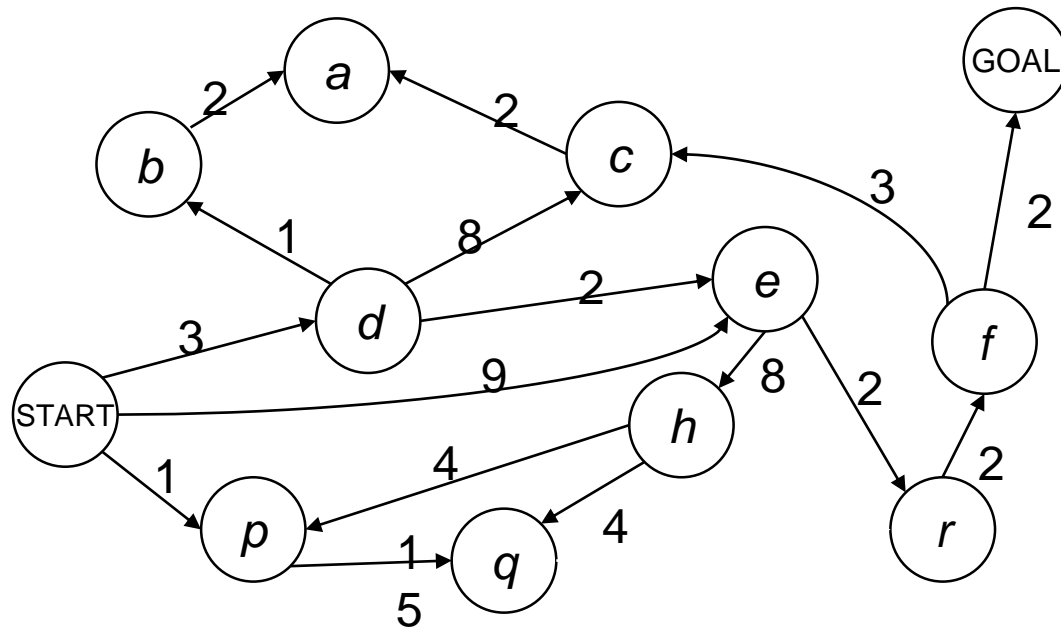


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 - Combines the low memory cost of DFS with the optimality of BFS

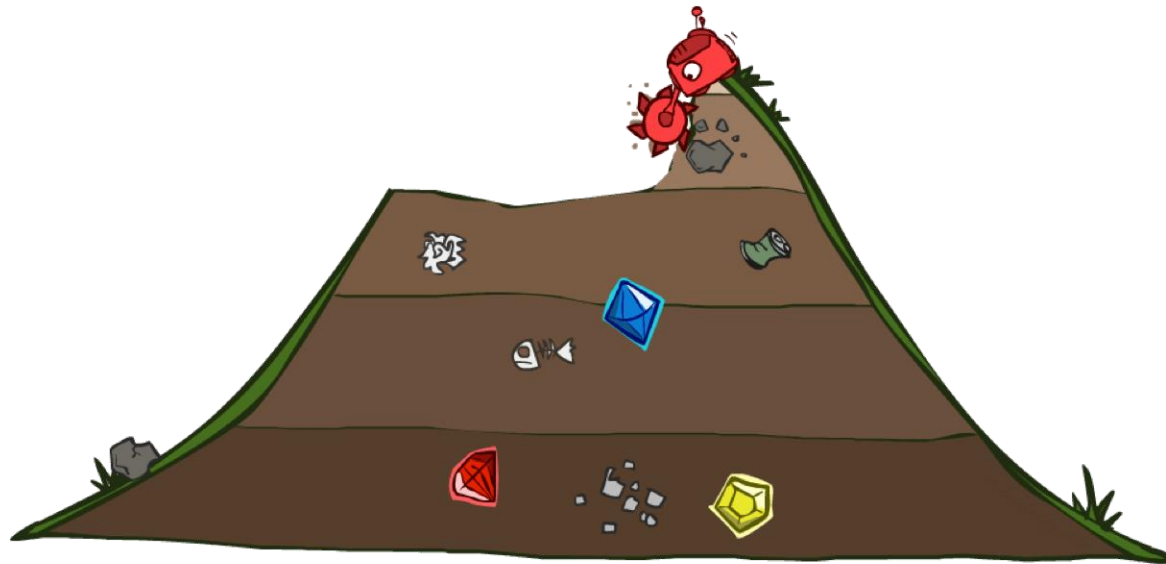


Cost-Sensitive Search



BFS finds the shortest path in terms of number of actions. It does not find the least-cost path. We will now cover a similar algorithm which does find the least-cost path.

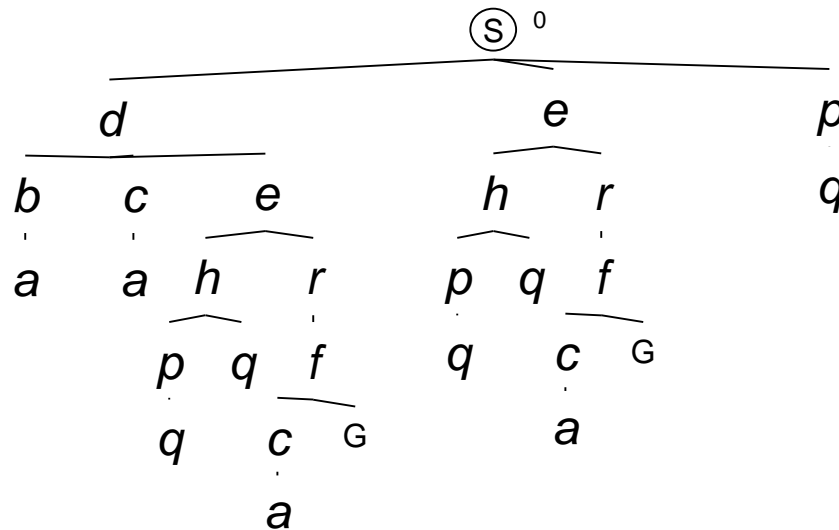
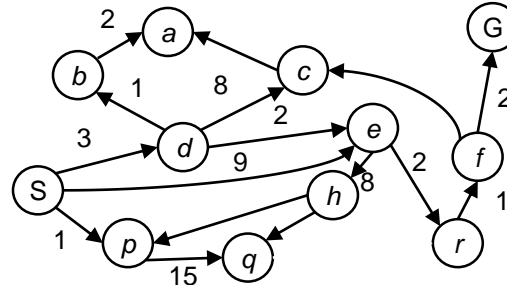
Uniform Cost Search



Uniform Cost Search

*Strategy: expand a
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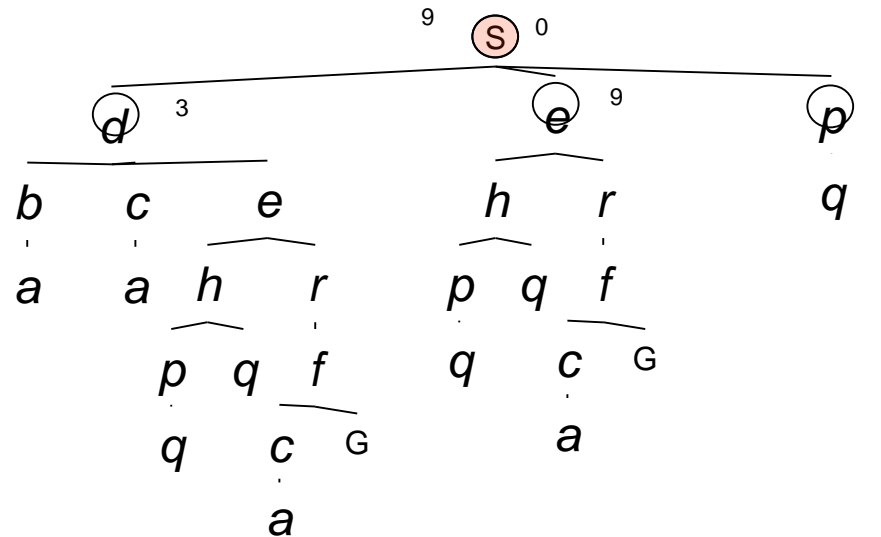
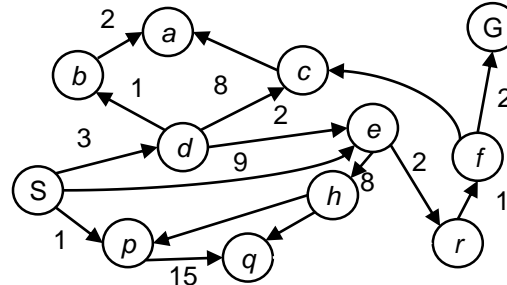
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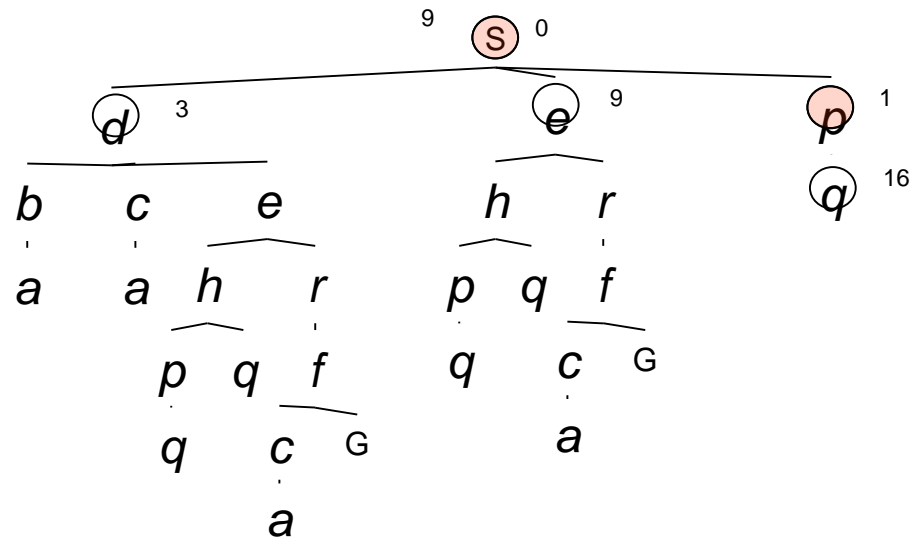
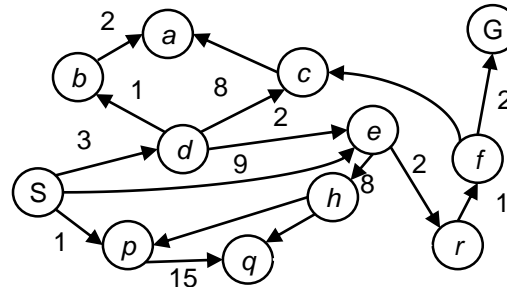
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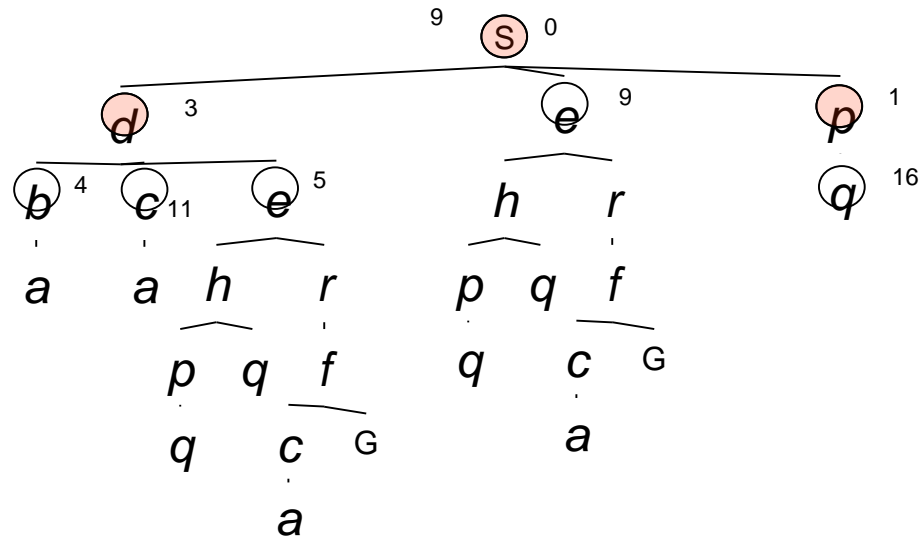
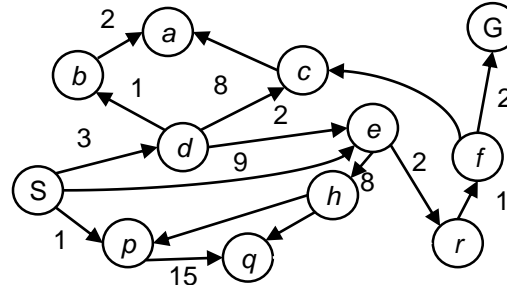
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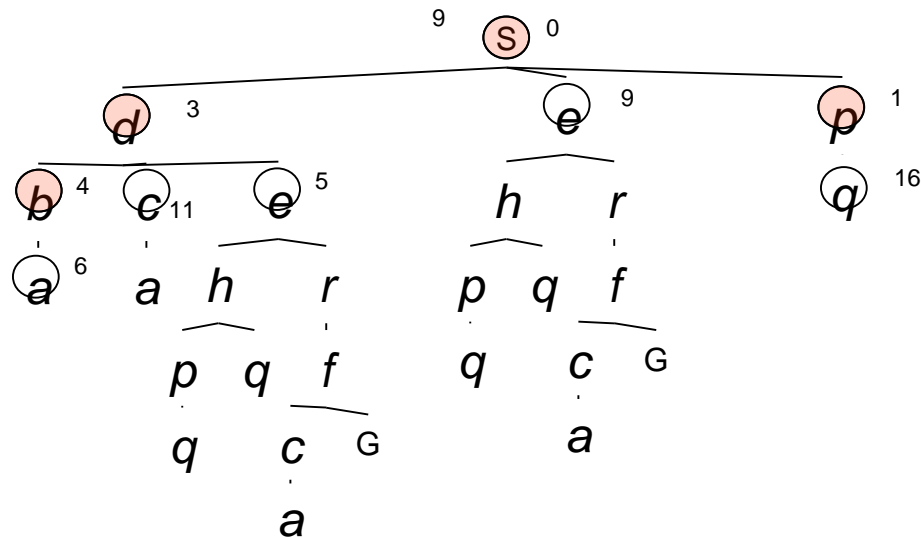
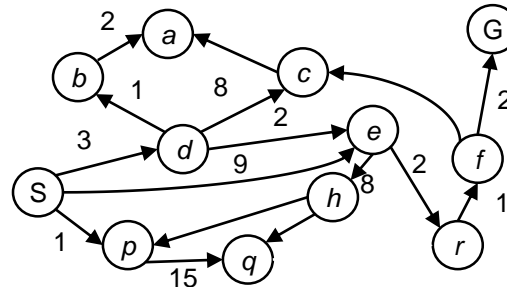
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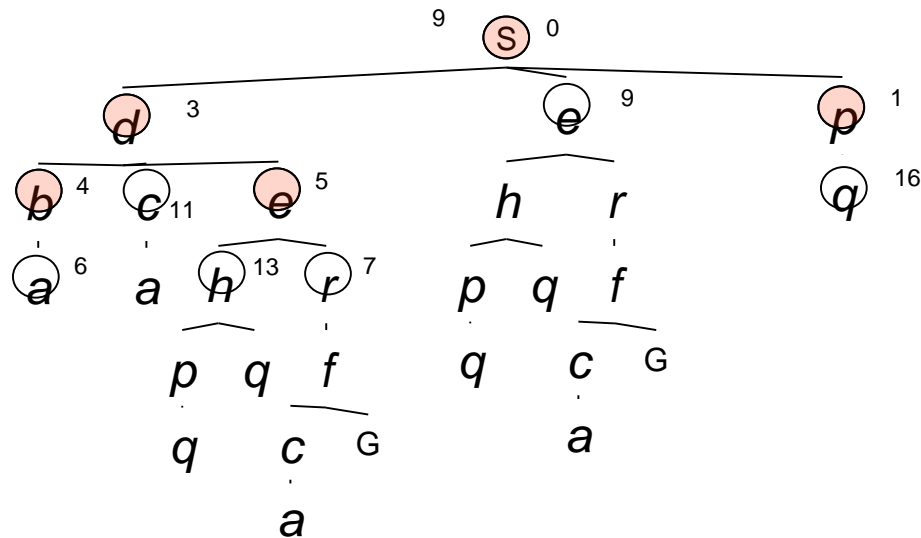
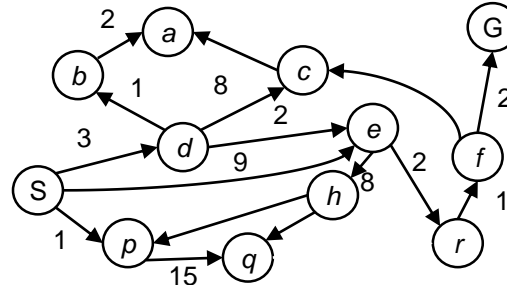
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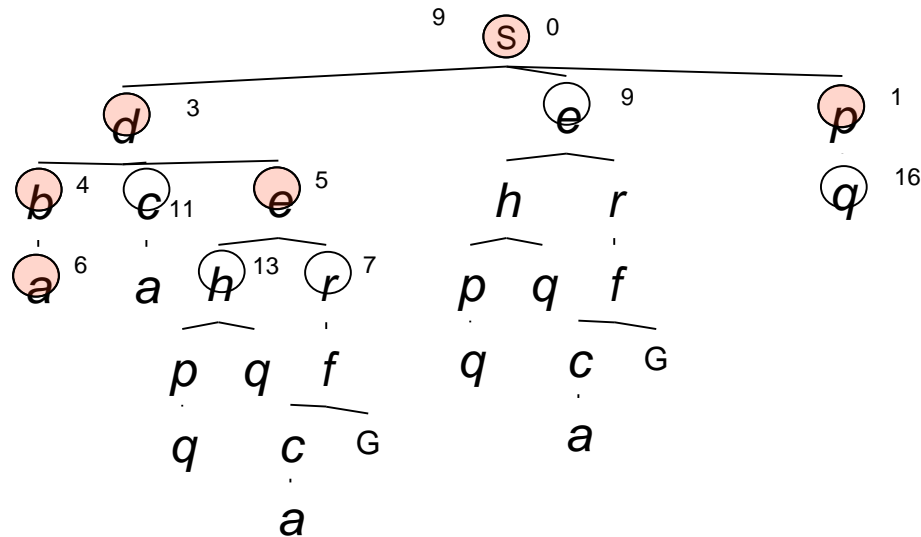
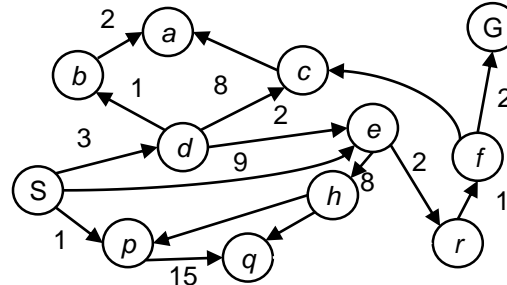
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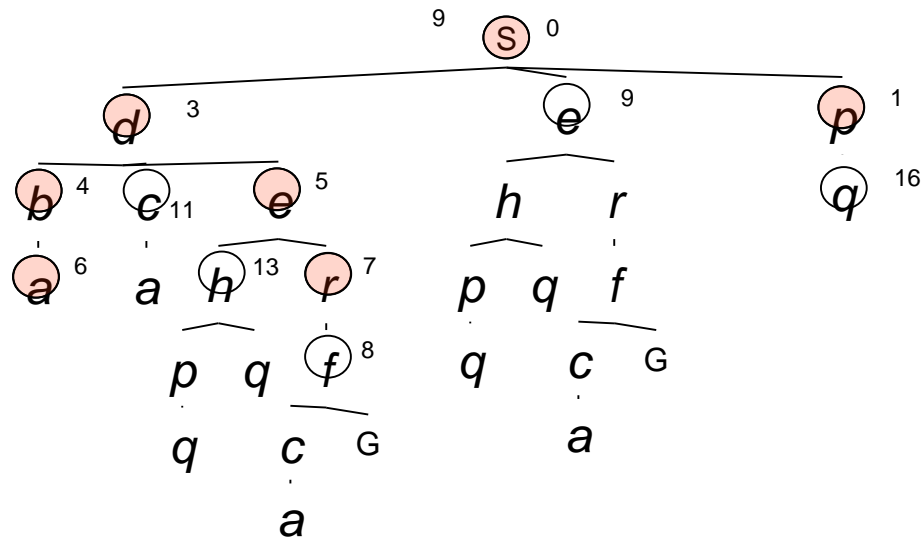
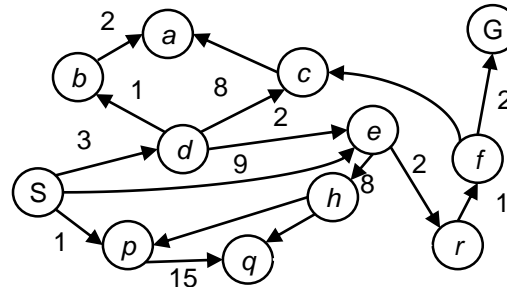
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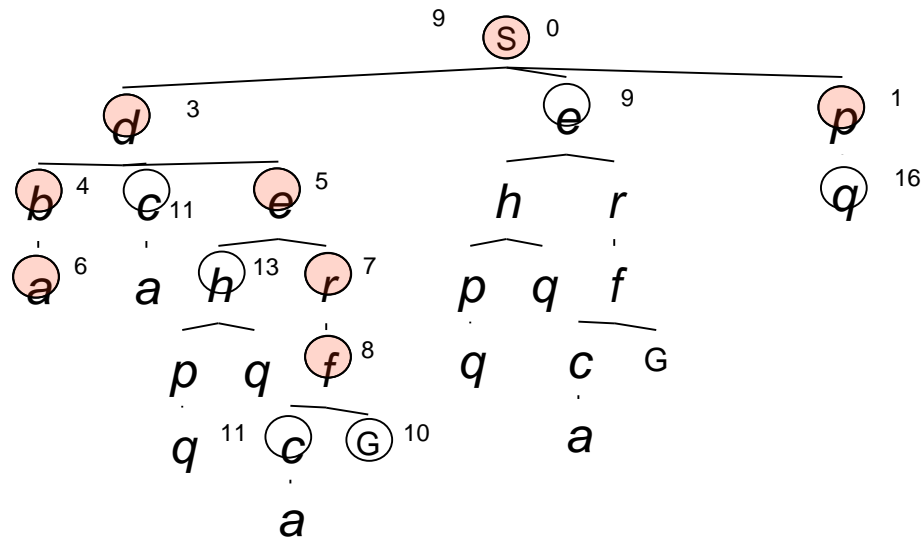
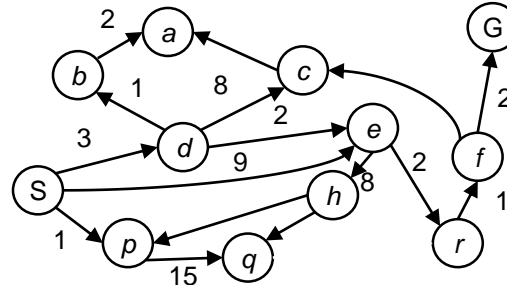
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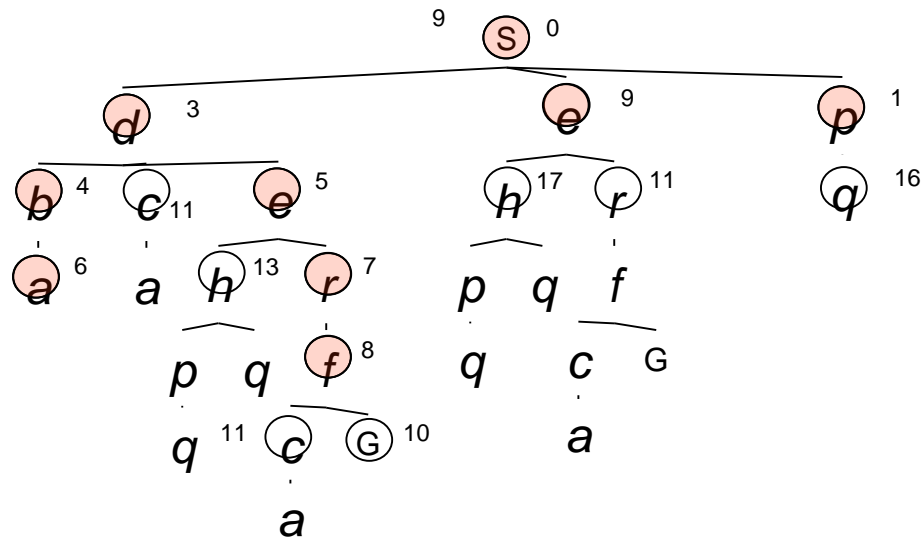
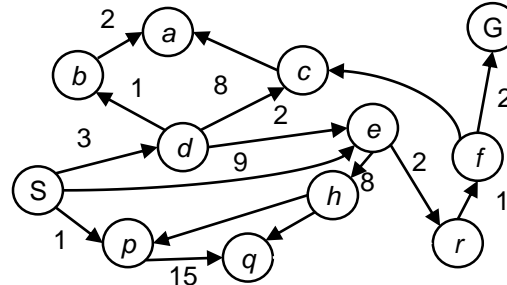
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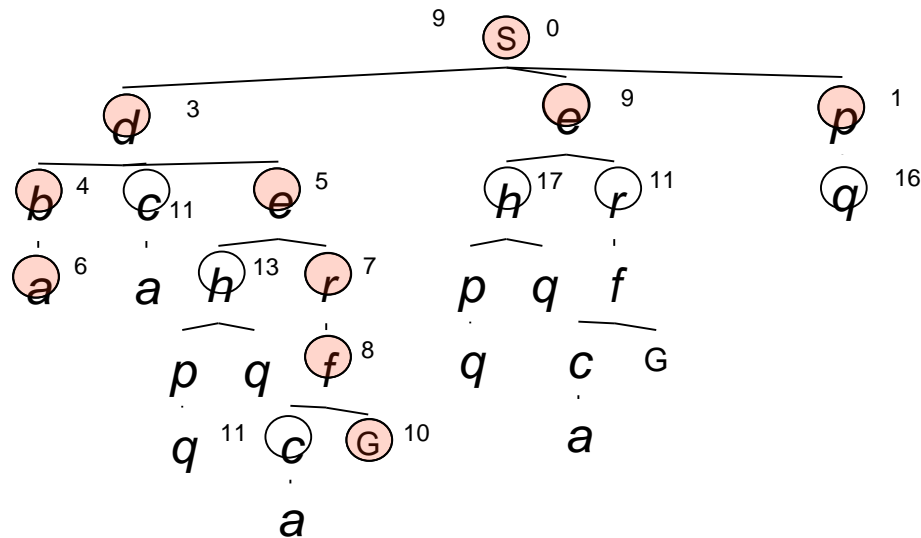
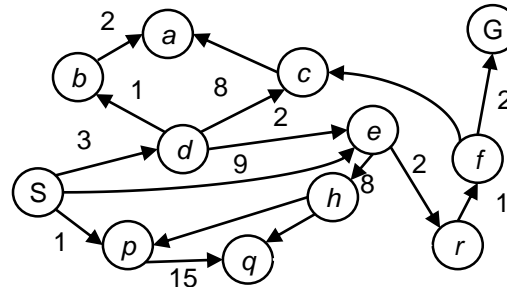
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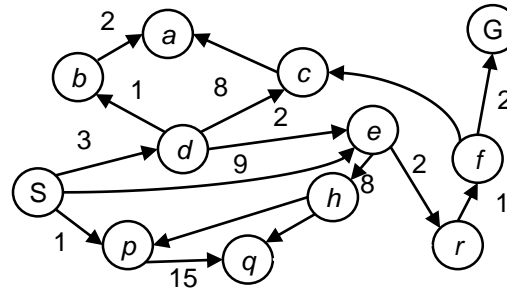
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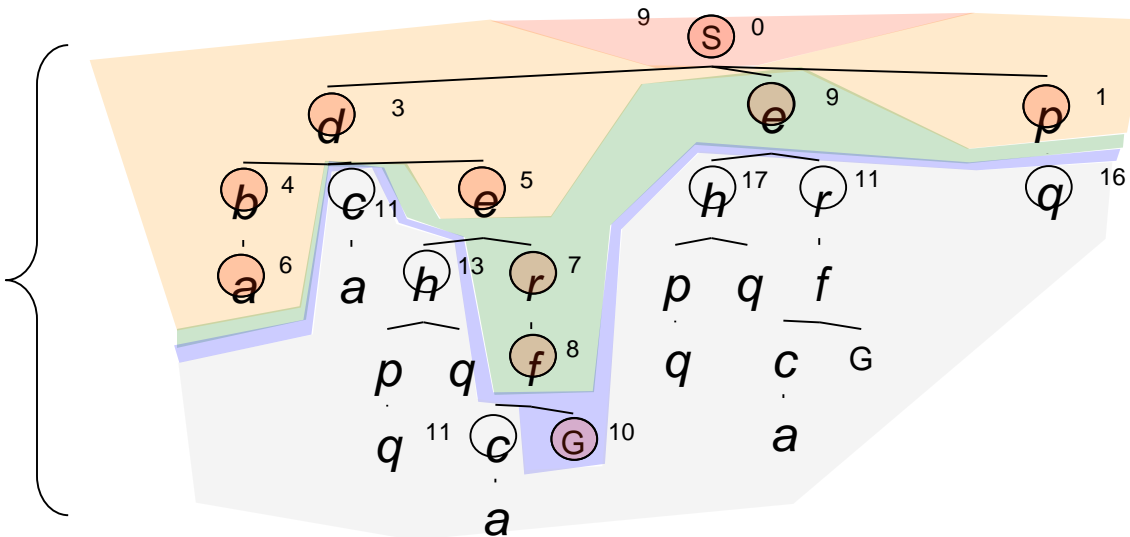
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*Fringe is a priority
queue (priority:
cumulative cost)*

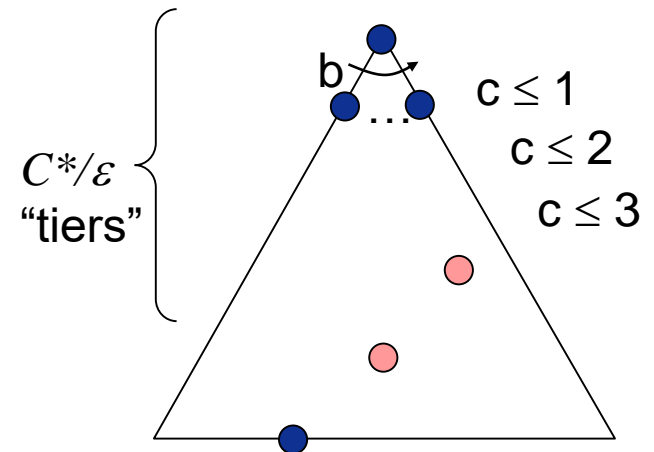


Cost
contours



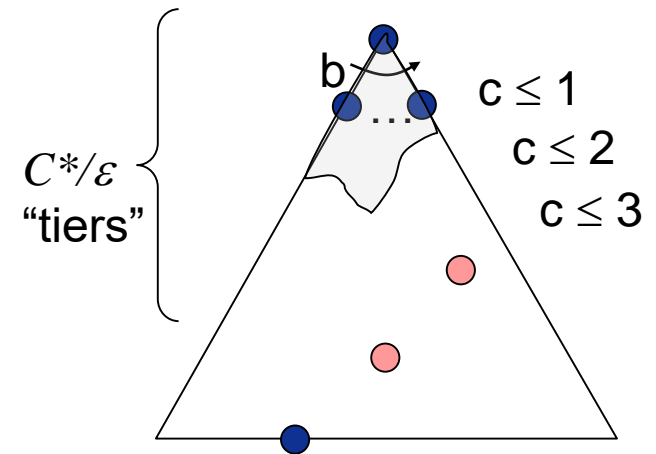
Uniform Cost Search (UCS) Properties

- What nodes does UCS expand?



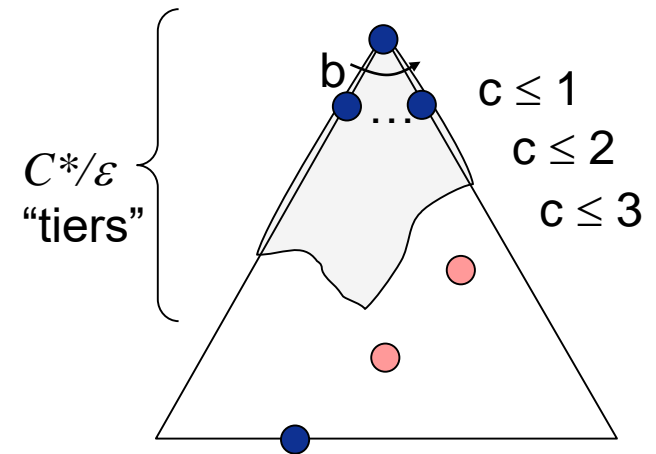
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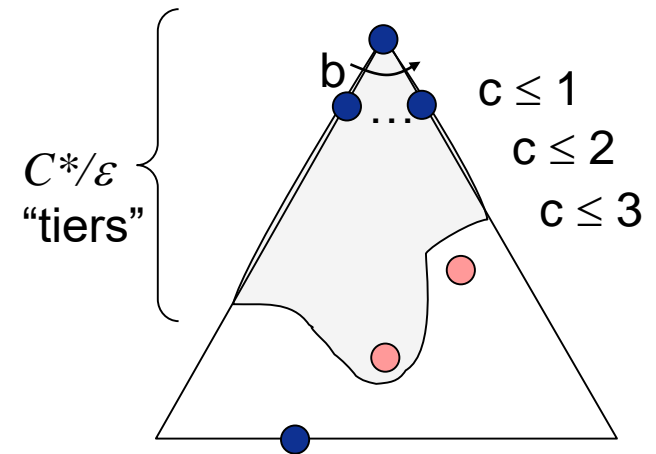
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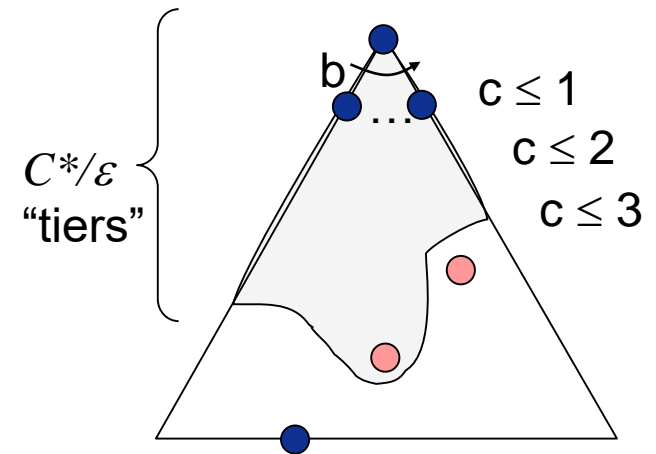
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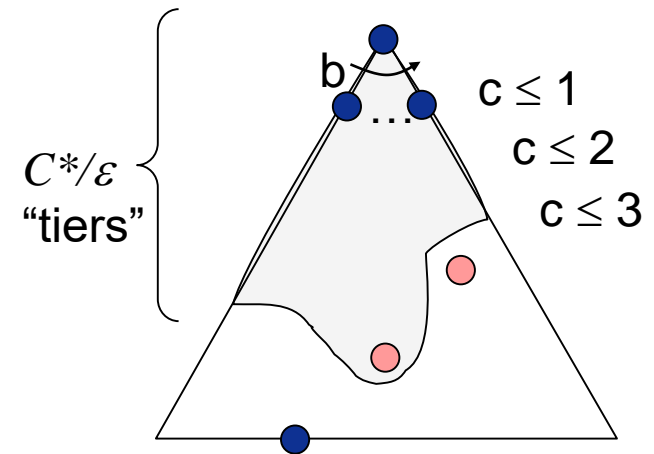
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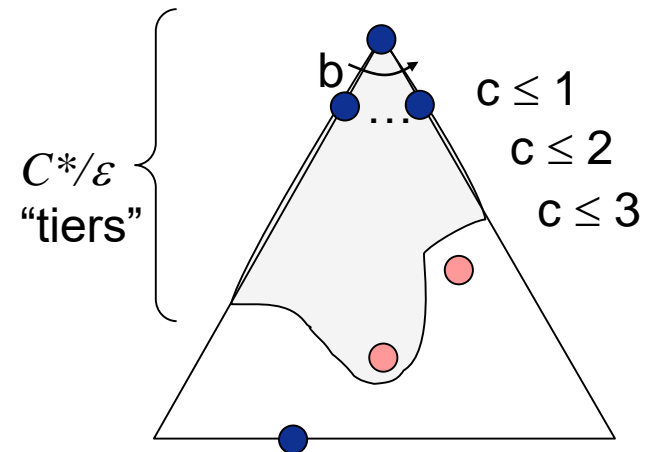
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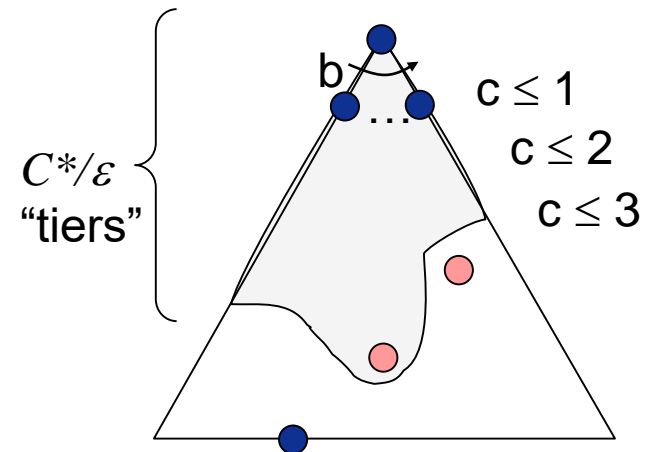
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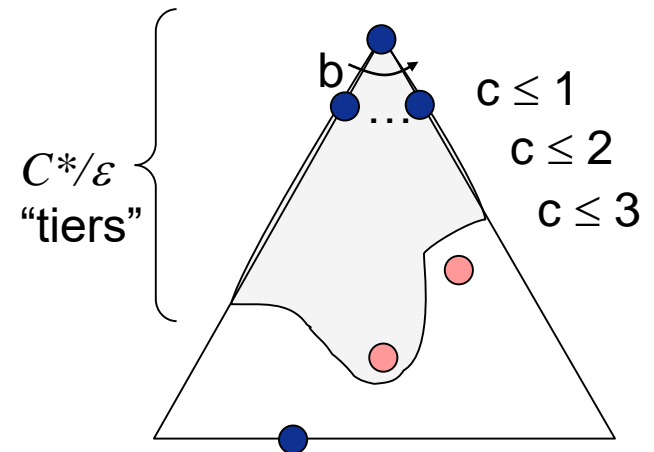
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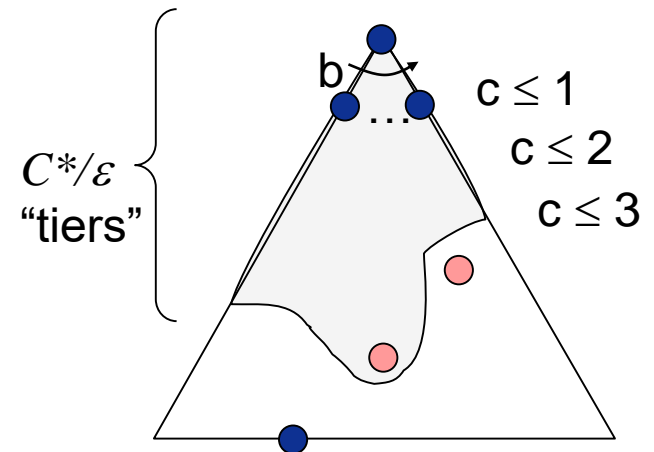
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- How much space does the fringe take?
 - Has roughly the last tier, so $O(b^{C^*/\epsilon})$



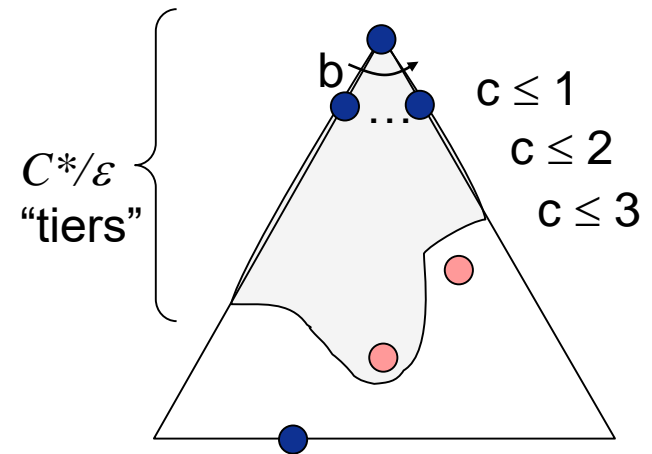
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- Is it complete?



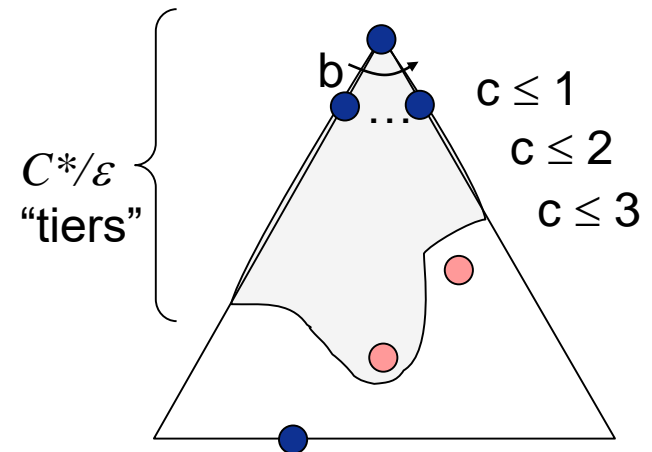
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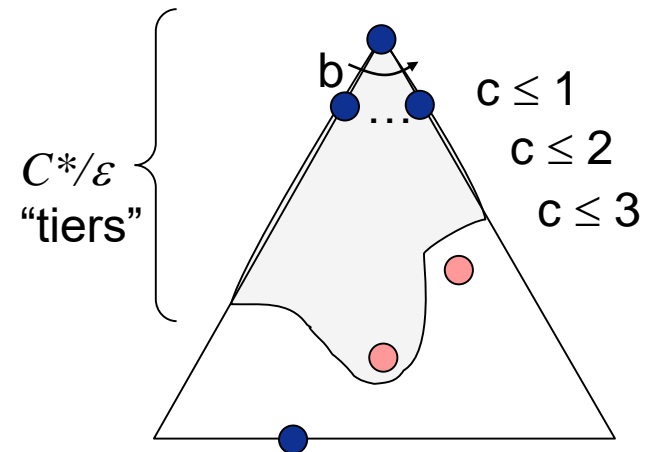
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- Is it optimal?



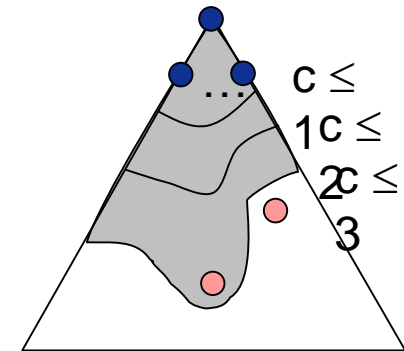
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 - Assuming best solution has a finite cost and minimum arc cost is positive, yes!
- Is it optimal?
 - Yes! (Proof next lecture via A*)



Uniform Cost Issues

- Remember: UCS explores increasing cost contours
- The good: UCS is complete and optimal!

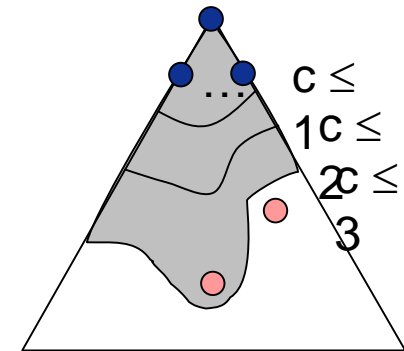


[Demo: empty grid UCS (L2D5)]

[Demo: maze with deep/shallow water DFS/BFS/UCS (L2D7)]

Uniform Cost Issues

- Remember: UCS explores increasing cost contours
- The good: UCS is complete and optimal!
- The bad:
 - Explores options in every "direction"
 - No information about goal location

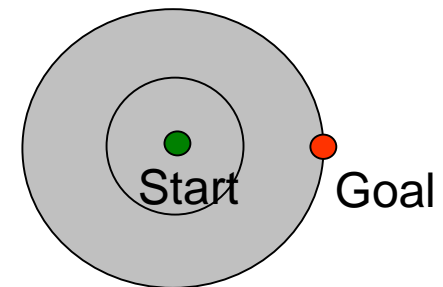
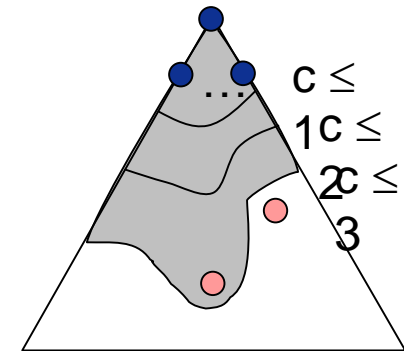


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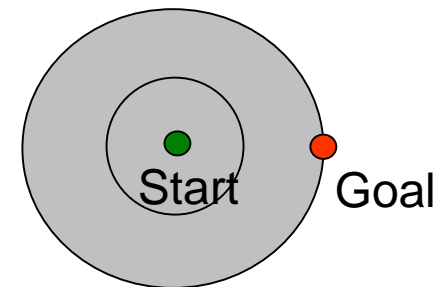
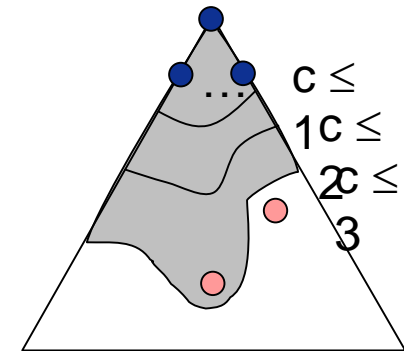


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Uniform Cost Issues

- Remember: UCS explores increasing cost contours
- The good: UCS is complete and optimal!
- The bad:
 - Explores options in every "direction"
 - No information about goal location
- We'll fix that soon!



[Demo: empty grid UCS (L2D5)]

[Demo: maze with deep/shallow water DFS/BFS/UCS (L2D7)]